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CORRELATION STUDY OF THE SIMULATION OF GEMINI EXTRAVEHICULAR ACTIVITY WITH FLIGHT RESULTS

by Harry L. Loats, Jr., G. Samuel Mattingly, and G. M. Hay

Prepared by
ENVIRONMENTAL RESEARCH ASSOCIATES
Randallstown, Md.
for Langley Research Center

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ABSTRACT

Prior to the Gemini IX mission all simulations of extravehicular activity were of a partial nature, mainly utilizing the zero gravity aircraft. This simulation technique did not provide adequate assessment of the biomedical factors of the performance of Gemini IX-XII. This problem was brought into sharp focus by the early cessation of Astronaut Cernan's extravehicular task on Gemini IX.

Concurrently, a NASA-LRC supported program of water immersion simulation was underway at Environmental Research Associates to investigate future ingress-egress requirements. This program was extended by NASA-MSC to include the postflight evaluation of the Gemini IX task and further to investigate the EVA of Gemini X and XI. The program culminated with Astronaut Aldrin performing preflight training and postflight evaluation of the successful GT-XII EVA.

The water immersion simulation of the Gemini EVA utilized full-scale mockups of the Gemini vehicle including portions of the Agena target vehicle with valid replicas of ancillary EVA equipment such as tools, astronaut maneuvering unit, etc. All important items were maintained in a neutrally buoyant condition. Bio-instrumentation was incorporated into the Gemini flight suits and continuous voice and film records were obtained.

The water immersion simulation of the Gemini extravehicular activity provided a valid training time line for performance of complex extravehicular tasks and provided adequate measures of the level of work entailed. A second capability evidenced as a result of the program was the method for evaluating various competitive hardware concepts such as tools and motion restraints. The technique used in the preflight evaluation and training was to perform the simulation run with ERA subjects prior to actual performance of the training run by the astronaut. This technique permitted pre-evaluation of hardware in a repetitive manner and served to assess the validity of the water simulation mode. Factors such as drag-damping and orientational stability were compensated by variation of the mockup orientation and configuration.

Subsequent to the flight, the time lines and the bio-medical data were analyzed to determine correspondences and differences. The results of the simulation program supported by an analysis of inflight data provides a performance baseline for future EVA tasks and critically evaluates the water immersion simulation technique for utility in future programs.

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INTRODUCTION

The early cessation of the EVA task of Gemini IX caused a reappraisal of the methods for preparing the astronauts for the flight and also of the techniques for planning EVA tasks. This reappraisal focused primarily on the inapplicability of the then existing simulations and training for long duration EVA tasks.

To address this problem, NASA extended a current water immersion EVA research contract with Environmental Research Associates to include an assessment of the GT-X EVA. When the simulation, performed by an ERA subject, closely approximated the actual flight performance it was decided to continue the program through GT-XI and GT-XII. The program further included a subjective evaluation of the simulation technique by an experienced astronaut. Cdmr. Eugene Cernan performed this function through a postflight evaluation of the GT-IX EVA.

Simulation of the GT-XI EVA, by ERA subjects, was used to identify problem areas and to schedule task sequence. Although the GT-XI EVA was not completed during the flight, a comparison of the resulting data emphasized the need for water immersion simulation and training. At this point in the program NASA included the water immersion training of the GT-XII EVA astronaut.

Calibrations runs by ERA subject and training runs by the prime and back-up crews were performed on a continuously updated mockup of the GT-XII flight configuration. Subsequent to the initial training run, major modifications were made to the EVA task which required additional training time and a rescheduling of the launch date.

Training for the final version of the GT-XII EVA using high fidelity hardware mockup was completed two weeks prior to launch. Biomedical measurements were made and a time line for the flight EVA was established. Finally, a postflight debriefing run was performed two weeks after mission completion by the astronaut.

The success of the Gemini XII EVA has led NASA to include water immersion training as an integral part of EVA mission training and a pool facility has been added to the MSC complex for this purpose.

Since the end of the Gemini program meant an end to all immediate EVA experiments contract NAS1-7142 was initiated by NASA-LRC and undertaken by ERA to correlate, as closely as possible, space experience and the simulation program. The following report presents the results and conclusions of this program.

1.0-PROGRAM SUMMARY

GEMINI EXTRAVEHICULAR TASK SIMULATION

Portions of the umbilical extravehicular tasks of four Gemini missions were simulated by water immersion techniques at ERA. These were the GT-IX, X XI, and XII missions. A summary of the specific tasks simulated is given in Table I.

The GT-X umbilical EVA was the first mission-task to be simulated, and was performed by an ERA subject wearing an Arrowhead version of the full pressure suit. This was followed by a postflight run of the GT-IX AMU donning task by Astronaut Cmdr. E. Cernan.

Subsequent to the performance of the GT-IX simulation, the complete task line of the GT-XI umbilical EVA was performed by an ERA subject. This was followed by the simulation of the original version of the GT-XII EVA performed by Astronaut Col. E. Aldrin. Subsequently, Astronaut Aldrin participated in extensive water immersion simulation - training of the final version of the GT-XII EVA.

Gemini X - The Gemini X EVA tasks were performed by an ERA subject wearing an air-pressurized Arrowhead, Mark IV Mod O full pressure suit. The task line included the connection of the HHMU nitrogen quick disconnect on the adapter and the placement and retrieval of experiment components located on the Agena TDA (the T-17, and S-010 experiments). The subject performed the HHMU-QD task by staging in a position representative of standing in the open hatch of the spacecraft, proceeding in a hand-over-hand fashion along the adapter handrail and connecting the QD while retaining a handhold. The subject routed the N_2 underneath the handrail prior to the connect task. A reverse order disconnect task was also performed.

The ERA subject also performed the T-17, S-010 placement task on the Agena TDA mockup. This task included transfering the T-17 experiment to the Agena TDA mockup, placing the T-17 on the velcro attachment pad on the Agena surface and retrieving the S-010 experiment. The S-010 experiment was transported from the Agena in two pieces by means of velcro attachment to the ELSS. The HHMU mockup was also carried on the ELSS by means of velcro attachment. Figure 1-1 shows a sequence of T-17 and S-010 experiment placement and retrieval. The ERA subject experienced great difficulty in handling and retaining experiment hardware during movement to and from the Gemini target vehicle.

Gemini IX - Astronaut Cernan commenced his AMU donning task at the umbilical pigtail connection on the circumference of the adapter curtain. He then proceeded to don the AMU to the point of the 180° turnaround prior to strapping himself into the AMU. The task included the activation of the AMU and ended with the chest restraint connection prior to release of the AMU, the point at which the abort *decision was made in flight. Figure 1-2 is an excerpt sequence from the film record of Cmdr. Cernan's performance. Water immersion simulation of GT-IX substantiated the validity of water immersion simulation as a tool for assessing spaceborne tasks.*

Gemini XI - An ERA subject wearing a pressurized G2C-FPS performed the GT-XI EVA tasks in sequential order. During an initial run it was determined that the sequence required modification due to equipment interactions. The resultant sequence of the Gemini XI EVA tasks was used during the subsequent simulations. Figure 1-3 shows a portion of the water immersion simulation of the GT-XI EVA. Early termination of the GT-XI EVA prevented a direct comparison of the results of the preflight water immersion simulation.

Gemini XII - Subsequent to the reconfiguration of the Gemini XII EVA, a series of simulations of the final version of the GT-XII extravehicular tasks was performed by Astronaut Lt. Col. Aldrin. Also included was a postflight simulation evaluation run by Astronaut Aldrin.

The mockup configuration comprised a full scale "visually-accurate" version of the Gemini reentry module including the R/R section and the adapter section plus a cylindrical section of the Agena TDA worksite.

The simulated GT-XII EVA comprised three basic sequences; (1) erection of the cockpit TDA handbar, (2) Agena TDA worksite tasks and (3) adapter worksite tasks. Figure 1-4 shows the planned task line for the GT-XII umbilical EVA which evaluated the astronaut's ability to work unrestrained and to work and rest, restrained by waist tethers, both in the spacecraft hatch and on the target vehicle. During this period the pilot connected the Agena tether and activated the S-010 micrometeorite experiment package located on the forward section of the target vehicle. The pilot then moved to the spacecraft adapter work station.

During the first night period, the pilot performed various subtasks at the adapter work station, alternately evaluating various restraint modes. The pilot exited the adapter at the start of the second daylight period and proceeded to the ATDA work station where he performed various subtasks. The pilot returned to the hatch after clearing the target vehicle and spacecraft.

TABLE I GEMINI EXTRAVEHICULAR SIMULATION TASK SUMMARY

MISSION	TASK	CONFIGURATION	ANCILLARY HARDWARE
GT-9	AMU Donning	Adapter end section	AMU (IX) with tether bag and penlight GT-9 foot restraints GT-11 foot restraints ELSS
GT-10	HHMU N_2 QD	HHMU QD panel Agena TDA half-section	HHMU T-17 S-10 and retention bracket EVA still camera ELSS
GT-11	EVA Camera placement Agena tether Foot restraint evaluation Apollo sump camera retrieval D-16 HHMU QD	Adapter end section and thermal curtain Reentry module R/R section	Apollo sump camera and brackets HHMU EVA movie camera and brackets EVA still camera ELSS D-16 with knee tethers GT-11 foot restraints Agena tether and clamp Docking bar mirror Debris cutters
GT-12-1	AMU Donning / Doffing AMU evaluation	Same as for GT-11	AMU (XII) with tether bag and penlights GT-12 foot restraints EVA movie camera and brackets AMU tether restraint clamps and attachments Debris cutters ELSS
GT-12-2	Handrail erection Adapter work tasks TDA work tasks	Reentry module R/R section Equipment adapter / work station Retro. adapter TDA / work station	Foot restraints / waist tether Portable handrail Adapter work station TDA work station Agena tether and locking clamp S-10 EVA movie camera

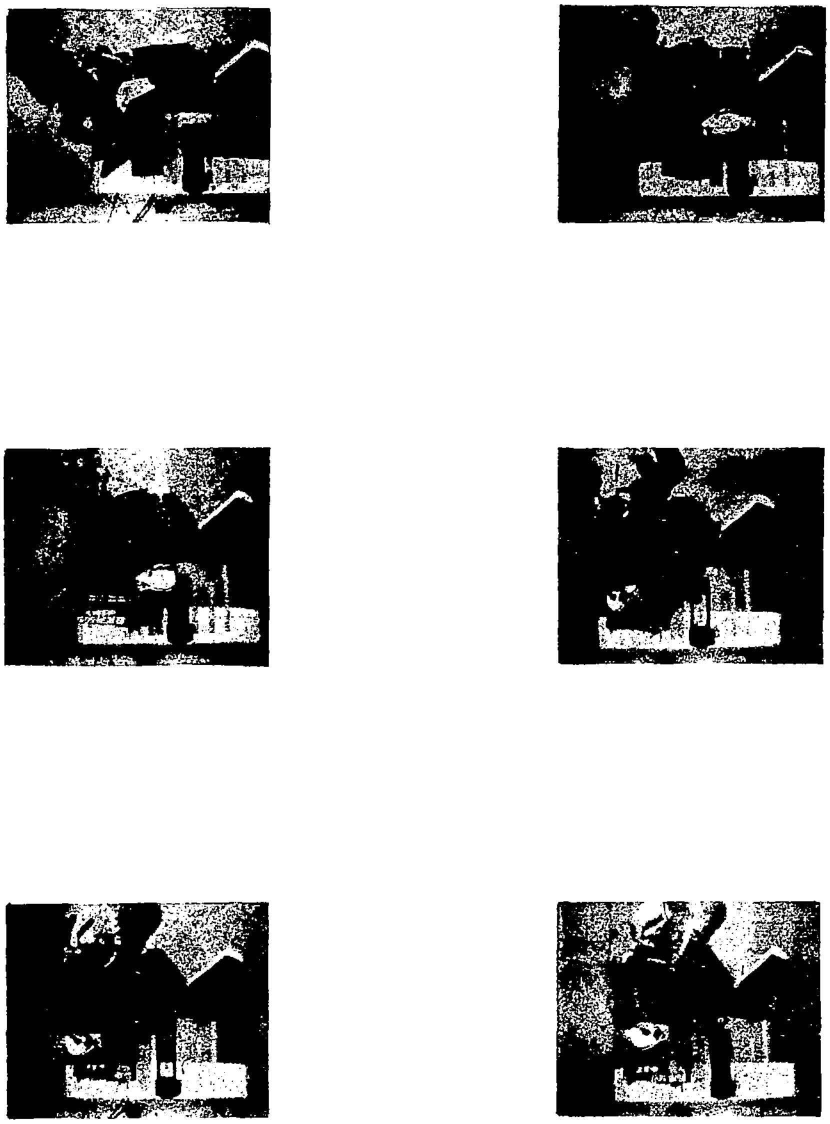


Figure 1-1 T-17 & S-010 EXPERIMENT PLACEMENT & RETRIEVAL

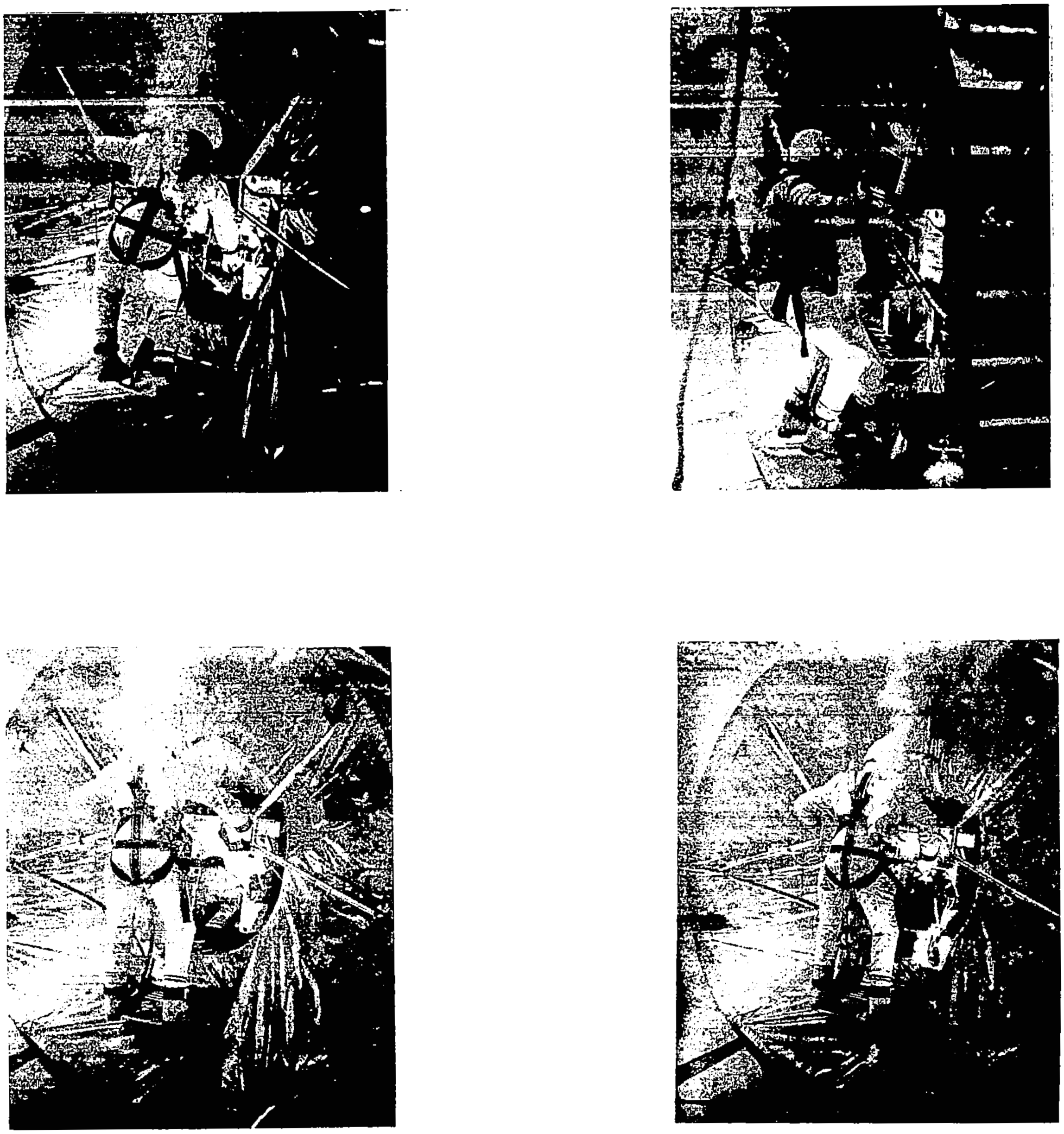


Figure I-2 AMU DONNING TASK

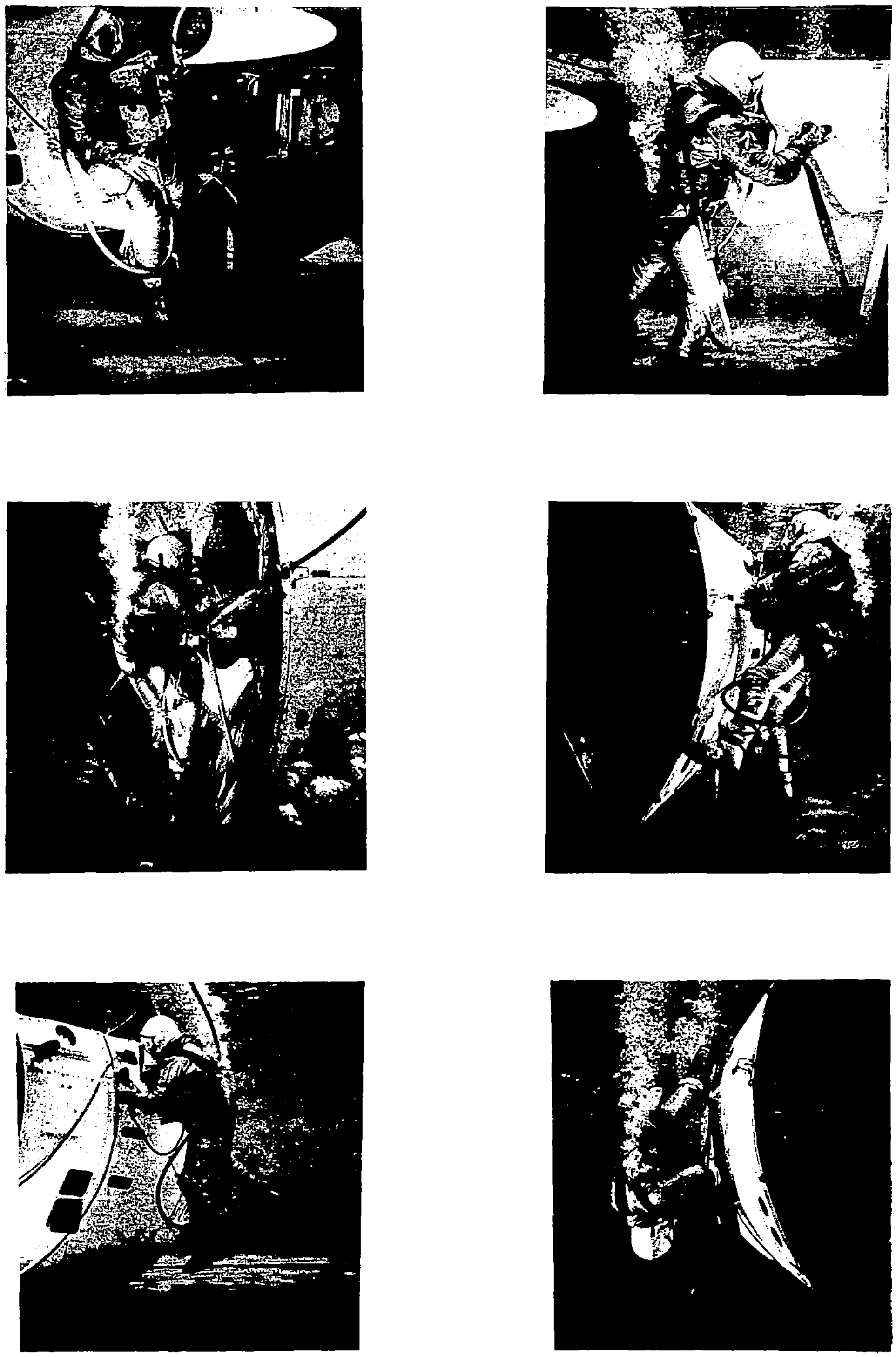


Figure 1-3 GEMINI XI SIMULATION SEQUENCE

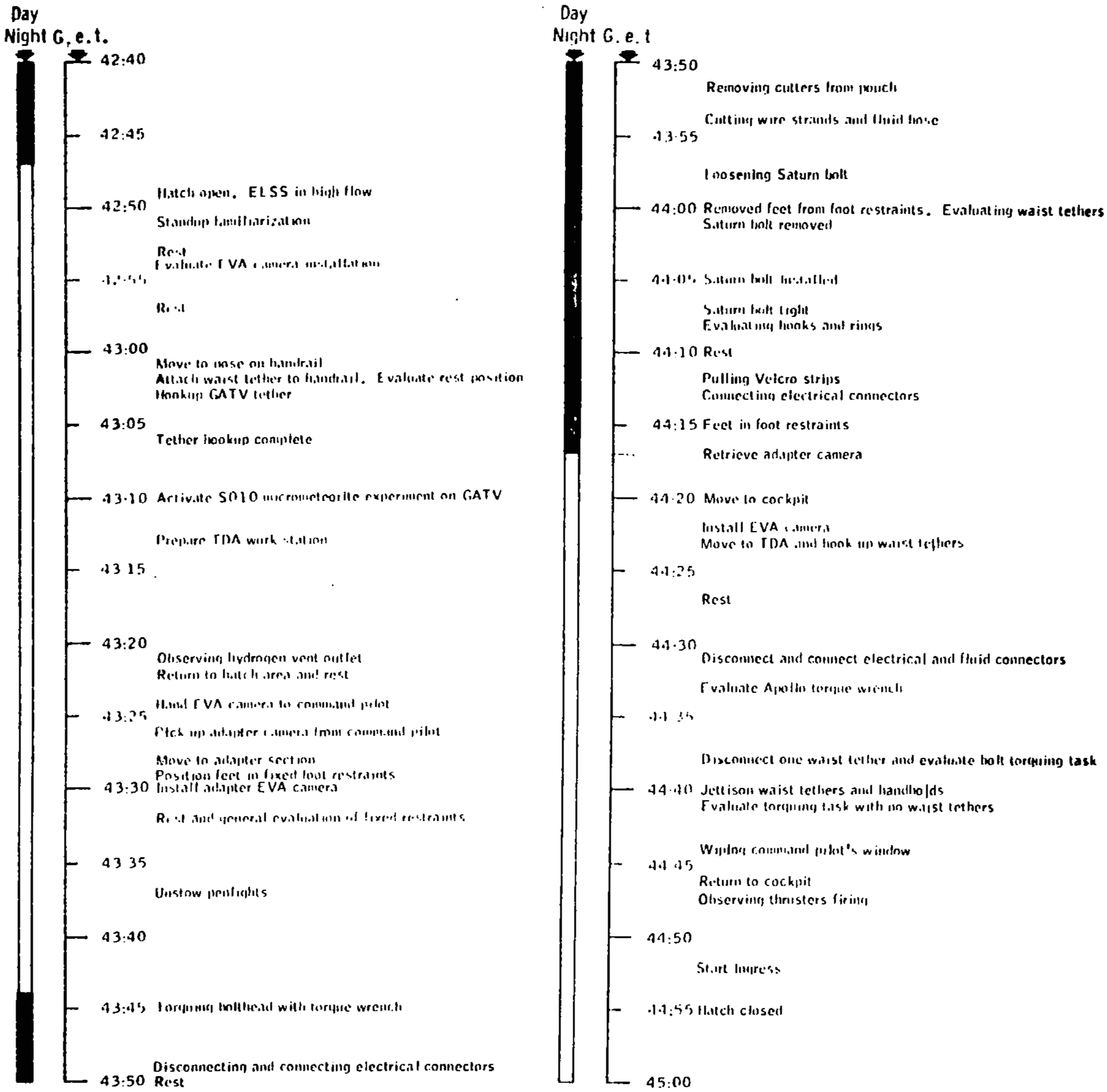


Figure I-4 GEMINI XII UMBILICAL EVA TIME LINE

2.0-WATER IMMERSION TECHNIQUE

The water immersion technique employed in Gemini simulation was developed by Environmental Research Associates and comprises the complete submersion of a subject in an air-pressurized single-gas anthropomorphic full-pressure space suit. The suit is maintained at a pressure of 3.7-4.0 psi above ambient water pressure by means of a relief valve mounted in the outlet port of the suit.

The complete weight of the subject and associated equipment is counter-balanced by the buoyancy forces acting on the subject exterior, i.e., the mass of the subject and equipment is adjusted to equal the total displacement. Since the suit when pressurized occupies a volume greater than the subject, ballast is required to achieve this condition of neutral buoyancy. The ballast is provided by means of distributed external wieghts, located to provide balance in roll, pitch, and yaw axes as well as maintaining the neutral buoyancy of the limbs. The water immersion technique has been demonstrated to be valid for low-velocity motions within restricted areas such as the Agena and spacecraft adapter work stations.

Successful application of water immersion to the Gemini Program was due in large measure to the experience gained in prior research programs and to careful consideration of recognized simulation constraints. The water immersion simulation technique is constrained by the following major factors:

(1) The effect of the fluid medium on the motion of the subject.

(2) The mass increase due to ballasting the subject.

(3) Attitude stability characteristics due to geometry of the subject.

(4) Metabolic effects of the suit pressurization system.

The fact that limb movement rates are constrained in a pressure suit and that safety considerations dictate that EVA be performed in a slow and deliberate manner greatly assist in minimizing the dynamic effects of the water medium. Experience at ERA has shown that subject velocities of less than one foot per second result in negligible displacements due to planing and that the drag forces are low as compared to the pressure suit forces necessary to induce the translational velocity. The pressure of the water drag force as a damping medium not present in space is a limitation which must be kept constantly in mind in evaluating the results of the simulations.

The damping effect of the water is somewhat offset by the necessity for the suit subject mass to be 30 to 40 percent higher than actual due to the ballasting required for neutral buoyancy; that is, the ballast inertia tends to compensate for the water damping and the response to the net force is similar in direction and magnitude to the same requirement in the space environment so long as the acceleration and velocity of the subject are relatively small.

The air volume of the inflated full-pressure suit allows the body position of the subject to change within the suit. The center of gravity of the suit-subject assembly is therefore a function of subject body attitude. The center of buoyancy for the suit-subject assembly is not altered by the shift of center of gravity. Misalignment of the center of buoyancy and the center of gravity results in rotation of the subject to a preferential attitude which aligns the center of buoyancy with the center of gravity along the gravity vector. Constant attention to this phenomenon and reballasting necessitated by gross attitude changes hold this preferential attitude effect to a minimum.

No attempt was made in these simulations to exactly duplicate the suit inlet and outlet gas environment as provided by the Environmental Life Support System (ELSS) chest pack in space. Air is supplied to the pressure suit subject via an umbilical containing the air supply line, air exhaust line, and electrical leads for biomedical measurements and voice communications. These items are encased in a normal umbilical flight cover with ballast weights added to achieve neutral buoyancy for the umbilical. The resulting umbilical assembly was slightly larger than the flight item but exhibited similar dynamic behavior.

An airflow of 10 CFM was used to assure adequate cooling and carbon dioxide removal from the space suit. The subject was biomedically instrumented with standard flight sensors to obtain electrocardiograms, respiration rate and depth, and body temperature on a continuous basis.

Figure 2-1 shows the system configuration developed for the simulation of the GT-XII umbilical EVA.

A full scale mockup of the Gemini spacecraft and target vehicle was utilized in the training-simulations. It consisted of a half section of the spacecraft reentry module, a 1/4 section of the spacecraft adapter shell, a full mockup of the adapter work station area, and a 1/2 section of the Agena target vehicle.

The spacecraft target vehicle area and spacecraft adapter work stations were full fidelity mockups utilizing training hardware identical to the flight items. Intervening areas were constructed to conform to the mold line configuration of the flight article. The mockup was located with the longitudinal center-line of the assembly 6 feet below the surface of the water. Figure 2-2 shows a representative mockup configuration in the ERA facility.

Auxiliary equipment included the Agena target vehicle work station equipment, adapter area work station equipment, astronaut tethers, and motion picture and still cameras.

Flight configuration work station hardware and tethers were used and no attempt was made to achieve neutral buoyancy in these items. The cameras were non-operating neutrally buoyant mockups of the flight hardware, but the attachment bracketry was identical to flight hardware.

The following personnel attended the suit-subject in the water for the Gemini XII simulation run.

2 - safety and equipment specialists
1 - simulation engineer
1 - test conductor
3 - photographers

Assisting in the simulation activities in the area outside the pool were:

3 - biomedical monitors
1 - command pilot
1 - flight plan specialist
1 - pressure suit specialist
1 - photographic specialist

All simulation personnel were in communication via a system of head-sets and an underwater loud speaker.

Data from the simulation consisted of:

(1) Continuous 16 mm color motion picture film

(2) Continuous tape recorded voice communications

(3) Biomedical data in continuous and/or tabular form

(4) Post run debriefing of the EVA astronaut

(5) Post run debriefing of simulation personnel

Each simulation session lasted approximately 3 1/2 hours and two simulations were performed each day. Gemini XII simulation schedule with Astronaut Major E. Adlrin as the subject was as follows:

September 12, 1966 - Simulation of the early task plan for the Gemini XII mission which included (1) attachment of the target vehicle tether and (2) preparation and flight of the astronaut maneuvering unit.

October 17, 1966 - Simulation of the revised Gemini XII task plan which included (1) attachment of the target vehicle tether, (2) operation of the adapter work station and (3) operation of the Agena work station.

October 29, 1966 - Simulation of final Gemini XII task plan. Emphasis on task time, task sequence and work load.

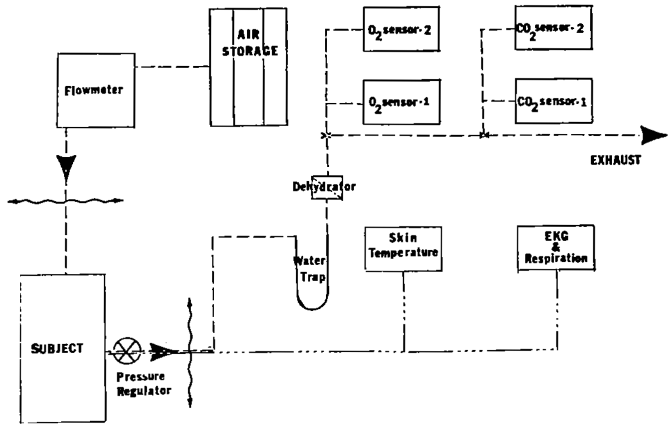


Figure 2-1 INSTRUMENTATION - FLOW DIAGRAM

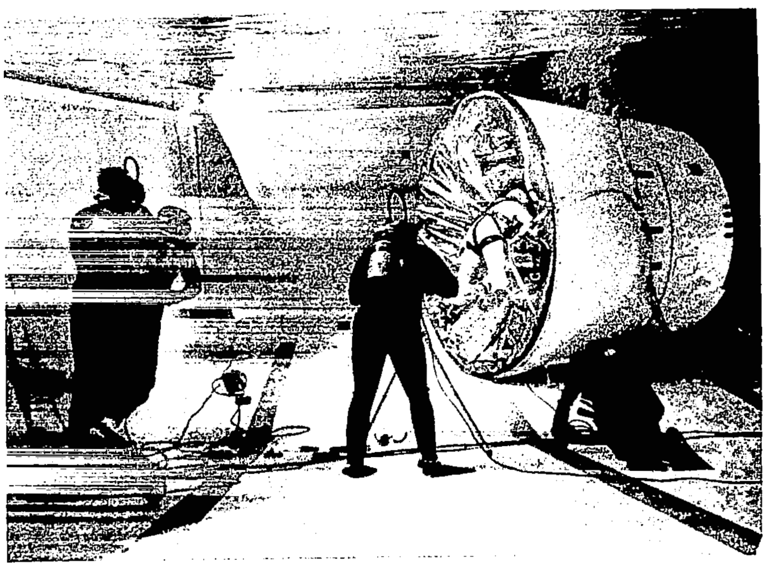


Figure 2-2 GEMINI III MOCKUP CONFIGURATION IN E.R.A. FACILITY

3.0-GEMINI EVA PROGRAM SUMMARY

The Gemini Program consisted of twelve flights, ten of them manned by two-man crews. Six of these flights had umbilical extravehicular activity by the pilot as part of their mission plan. These flights are shown in Table II.

Additional standup EVA was accomplished on these flights with the pilot standing in the open spacecraft hatch. The EVA portion of the missions was completely or partially accomplished on all flights except Gemini VIII, which was terminated before the scheduled EVA due to a spacecraft malfunction.

The three objectives of EVA on the Gemini Program were:

(1) Develop the capability for EVA in free space.

(2) Use the developed EVA capability to increase capability of the Gemini spacecraft.

(3) Develop operational techniques and evaluate advanced equipment in support of EVA for future programs.

In general, the principal objectives were met but problems encountered during the program somewhat shifted the emphasis on the objectives. The evaluation of various free space propulsion devices was deferred in order to obtain a better understanding of tether dynamics, body stabilization requirements, operation of the pressure suit system, and control of metabolic energy loads.

One of the most difficult aspects of developing an extravehicular capability was simulation of the EVA environment. The combination of weightlessness and high vacuum is unattainable on earth. Zero gravity aircraft simulations were extensively used and proved valuable but occasionally misleading. Neutral buoyancy simulations underwater ultimately proved to be the most useful duplication of the weightless, tractionless aspect of the EVA environment as experienced by the Gemini astronauts.

The flight plans and tasks for EVA were different for each Gemini mission so the widest possible experience could be obtained in the limited flights available. This diversity of flight activities made the success of the program highly dependent on good simulation of the EVA environment for development of the flight plan and equipment and for training of the EVA astronaut.

Simulation for Gemini IV, VIII and IX-A consisted of flights in the zero gravity aircraft for astronaut training and equipment procedures development; and one gravity walkthrough for flight planning development, stowage development, and astronaut procedures training.

Gemini X and XI had the benefit of water immersion zero gravity simulation for flight planning and equipment evaluation from simulations performed by the Environmental Research Associates pressure suit-subjects and made available to the Gemini flight crews in motion picture films. Gemini XII, the last Gemini mission, had the full benefit of water immersion zero gravity simulation in the form of:

(1) Real time, full length task line development utilizing both the EVA pilot and the command pilot.

(2) Extensive pressurized spacesuit operating time in a tractionless environment for the EVA astronaut.

(3) Biomedical surveillance of the EVA astronaut during simulation to enable proper flight planning of the EVA work load.

Problems Encountered During EVA - While the majority of the EVA mission objectives were met on each flight, each had minor discrepancies worthy of note to those interested in the planning required by such a unique activity.

The first entry into extravehicular activity was performed on Gemini IV by Lt. Col. E. H. White. The only difficulty he encountered was in closing the spacecraft hatch at the end of the EVA. A much higher level of effort was required than had been encountered in aircraft and ground simulation, resulting in rather severe overheating of the EVA pilot and to some lesser extent the Command Pilot who had to assist.

The Gemini IX-A mission objective, to evaluate a stabilized maneuvering unit during EVA, was not achieved because Astronaut Cernan's high metabolic heat load caused visor fogging, resulting in restricted vision. The high heat load was due to difficulties in maintaining body position during the maneuvering unit preparation activities. These difficulties were unexpected in that the Gemini IV EVA and the Gemini IX-A training in the zero gravity aircraft had not identified the extent of the difficulty in maintaining body position.

The body positioning problem occurred again on Gemini X but did not have a significant effect on performance. The work load and positioning problem became increasingly more important after the Gemini XI mission. Severe heating and sweating of the astronaut in conjunction with body positioning problems with activation of the Agena tether caused an early cessation of the umbilical EVA.

Major Results of Water Immersion Simulation of Gemini EVA - The water immersion simulation of zero gravity had been used previously by NASA as a research tool and as a result of Gemini IX-A, was quickly established as an engineering and task planning tool in support of future Gemini flights.

A relatively low fidelity neutral buoyancy simulation of Gemini X EVA part tasks revealed no unexpected difficulty and none was experienced by Astronaut Collins on the Gemini X flight except stowage and housekeeping difficulties which resulted in loss of some equipment. The neutral buoyancy simulation of the Gemini XI EVA task plan revealed that movement along the vehicle while burdened with many loosely tethered items of equipment resulted in a high probability of equipment loss and possible entanglement, as had been experienced on Gemini X. As a result, two bulky items of equipment were deleted to enhance the chances for recovering the data from experiments in the adapter. No difficulty was experienced with the target vehicle tether attachment task during the neutral buoyancy simulation of Gemini XI EVA, where the task was conducted as a one hand operation with the other hand used on the docking bar to maintain a floating stability.

During the Gemini XI flight EVA Astronaut Gordon exceeded the capability of the EVA Life Support System, resulting in excessive fatigue, overheating, and possibly exceeding acceptable CO_2 levels due to high metabolic loads. The high metabolic loads were generated while attempting to maintain body position to accomplish the task of attaching the target vehicle tether. The body positioning technique of using the legs to hold position on the spacecraft nose was successfully simulated in aircraft and 1G training but proved too fatiguing in flight. Had the astronaut used both neutral buoyancy and aircraft zero gravity simulation for his training the problem would most likely have been discovered.

Gemini EVA experience through mission XI led to the following conclusions:

(1) *Engineering and task analysis preflight planning of the EVA missions had been inadequate to completely define the difficulties encountered.*

(2) *When unexpected difficulties were encountered in flight they resulted in body positioning problems and a large increase in metabolic load as the astronaut powered the space suit in an effort to maintain body stability.*

(3) *The astronaut could generate metabolic loads which exceed the capability of the EVA Life Support System resulting in degraded performance.*

(4) *The EVA astronaut should use neutral buoyancy simulation for training in addition to zero gravity aircraft flights.*

(5) *The Gemini XII should be devoted to defining and resolving the body restraint problems by means of a series of varied tasks, while assuring metabolic loads within Life Support System capability.*

These conclusions resulted in the requirement for a high fidelity, neutral buoyancy simulation of the Gemini XII umbilical EVA to be flown by Astronaut Aldrin. This simulation would address both engineering and crew training aspects.

TABLE II

Summary of Umbilical EVA Activity of the Gemini Mission

MISSION	EVA ASTRONAUT	DATE	DURATION
GEMINI IV	LT. COL. E.H. WHITE II	JUNE 3, 1965	36 min.
GEMINI VIII	LT. COL. D. R. SCOTT	MARCH 16, 1966	-
GEMINI IX-A	CMDR. E.A. CERNAN	JUNE 5, 1966	2 hrs. 7min
GEMINI X	MAJOR M. COLLINS	JULY 20, 1966	39 min.
GEMINI XI	LT. CMDR. R.F. GORDON	SEPT. 13, 1966	33 min.
GEMINI XII	LT. COL. E.E. ALDRIN	NOV. 13, 1966	2 hr 6min.

4.0-PERFORMANCE ANALYSIS

Water immersion simulation had been used by ERA prior to the Gemini simulation program for general research purposes. The main tasks investigated were ingress-egress through airlocks and passageways. In this research program the intent was to measure the interactions between a subject pressurized in an anthropomorphic full-pressure suit and the surrounding airlocks and passageway structures. No attempt was made to ascertain metabolic requirements.

The primary advantage of water immersion and the main factor which recommended it for use in the Gemini program, was the relative insensitivity of the simulation mode to task length. Its major drawback appeared to be that since the subject was maintained in a one gravity environment within the suit and only the external tractionless aspects of weightlessness were simulated, the metabolic determinations were unjustified.

Other versions of water immersion simulation, the water filled suit technique, partially compensate for this restriction since the density of the human body approximates that of water. The water filled suit technique, however, suffers a greater handicap, in that suit mobility is altered due to the incompressibility and viscosity of the water pressurizing media. This latter factor exercises a far greater degradation of the simulation since the primary factor under investigation is suit mobility in weightless environments.

4.1 - GEMINI X - Although the problem of valid simulation first arose in conjunction with the early cessation of the Gemini IX EVA, the first use of the water immersion technique was a portion of the GT-X umbilical EVA task.

The primary objective was the retrieval of an experiment package of the GT-VIII target vehicle previously left in orbit. Astronaut Collins translated through free space by means of the tractor-type propulsion unit (HHMU). Figure 4-1 shows the equipment mockups used during the water immersion simulation of the nitrogen umbilical supply line-coupling and disconnect, T-17 placement and S-010 retrieval.

All water immersion simulation of the GT-X tasks were performed by ERA personnel wearing Arrowhead, Mark IV full-pressure suits. The three umbilical EVA tasks were simulated numerous times in a manner specified by NASA flight crew training personnel. During the performance of the simulations various astronauts were present and acted as observers, and performed certain parts of the task in SCUBA. Film records of the simulations were viewed by the Gemini X flight crew. The important aspects of the simulated task performance are summarized below:

(1) The subject wearing the FPS "stages" from a standing position in the pilot's seat.

(2) The subject activates the handrail on the adapter.

(3) The subject, wearing an ELSS with the HHMU velcroed to it, egresses the Gemini and proceeds in a hand over hand manner down the adapter handrail to the location of the disconnect panel.

(4) The subject opens the storage panel of the HHMU-N_2QD by a pinch-action on the fastener in the face of the panel. Subsequent to panel release, the subject throws the panel away.

(5) Taking the HHMU-N_2QD in one hand, retaining a hand-hold on the handrail with the other, the subject effects a connection of the QD with a pushing motion.

(6) Upon successful QD operation, the subject rotates the nitrogen on-off valve which had been made automatically accessible by panel removal. This activation involves the 90° rotation of a small handle located near the QD.

(7) Removal of the QD occurs in a reverse manner. The release of the QD occurs in response to a "light" push on a release lever integral with the QD.

Various general conclusions concerning the simulation technique and operation were made by the ERA and NASA project engineers. It appeared that the mockups supplied to ERA by MSC were inadequate to determine the total character of task performance. The mockup duplicated only small portions of the spacecraft, approximately one square foot of the adapter surface and a small length of a half section of the target docking cone area. These sections were insufficient to determine complete body interaction with the spacecraft.

Several important factors were determined. (1) A new routing technique was specified for the nitrogen umbilical supply line to prevent astronaut entanglement and to control the location of the disconnect, (2) serious hardware-spacecraft interactions were observed wherein various loosely attached elements were continually being snagged by protruding hardware and lost during movement to and around the target vehicle, (3) it was observed that the handholds and motion aids on the target vehicle were inadequate to permit the astronaut to properly retrieve and activate experiments (particularly the S-010 micrometeorite collector), and (4) the subject's feet continually contacted the spacecraft as a result of the natural tendency of the suit when arm motions were involved. This latter factor was in disagreement with the reports of Astronaut Cernan, who had experienced body positioning difficulty; his feet and body continually moved away from the spacecraft.

No attempt was made to determine the metabolic requirements of the task since the Navy Mark IV FPS was used and a continuous task line simulation was not performed. NASA personnel used the film record of the simulation in a qualitative manner to acquaint the crew with the visual aspects of the task performance. At this time, the flight crew felt that the motions evidenced in the water immersion simulation would not be replicated in flight.

Subsequently, a quantitative measurement of task time and body-hardware contacts was made by ERA in preparation for correlation with data from the flight. As it turned out there was no flight film due to camera malfunction so that the voice record and the postflight debriefing were the only information that was analyzed.

The Gemini X umbilical EVA began after rendezvous with the Gemini VIII target vehicle. After retrieving the S-012 micrometeorite package the pilot proceeded to connect the HHMU nitrogen supply line. The S-012 retrieval was not simulated in the water. After returning to the cockpit the astronaut prepared to transfer through free space to the target vehicle. With the Gemini vehicle and target in close proximity (approximately 5' separation) the astronaut pushed off toward the target vehicle grasping the outer lip of the docking cone.

Verbal description of the maneuver ascertained that the ERA subject had accomplished this maneuver in a similar fashion. The astronaut lost his hold on the smooth docking surface and drifted away from the vehicle, returning by means of the HHMU. He then used appurtances on the docking cone as handholds and proceeded to accomplish experiment retrieval. Similar performance had been observed in the simulation. Table III presents the results of the data analysis of the simulation run.

The GT-X umbilical EVA had the following major results:

(1) It marked the performance of the first work task by an astronaut in space and also first transfer between spacecraft.

(2) The astronaut performed an abbreviated EVA with relative ease.

(3) The performance of the EVA was incomplete and data return degraded by a malfunction of camera and the loss of camera and micrometeorite package.

(4) The astronaut experienced relative difficulty in moving along the spacecraft due to inadequate restraint and handholds and perturbation to the passive target vehicle.

The work loads evidenced were relatively low and only during ingress and hatch closure were elevated heart rates and respiration rates noted (peak respiration rate = 34/min., peak heart rate = 160 min.).

In general, the flight performance correlated very well with the preflight simulation taking into account the difference in suits and also subject differences. The astronaut was required to route the nitrogen umbilical in a slightly different manner than planned because the aft handrail did not fully extend. Astronaut Collins stated in the postflight debriefing -

> Collins - "As far as the nitrogen line hookup went, it was not very difficult, but it was not very easy either. The half of the quick disconnect on the umbilical itself has a sleeve around it, and this sleeve must be in the retracted position in order to have it cocked so that you can make the disconnect connection. The first time I took a stab at it, I hit the fitting on the side of the spacecraft a little bit off center - a little bit off axis, and that snapped this collar down to the engaged position, and in this configuration it will not lock in place. So, that meant I had to go back and recock it. This takes two hands, and so I had to let go with both hands for not more than 3 seconds to get that thing recocked, and then on my second attempt I did make the QD without any trouble, and then I turned on the nitrogen valve In general, the body positioning was not quite as difficult I think, as I had been led to believe by some of these water tests and what not, but on the other hand it wasn't a very easy thing either particularly because I was using the forward handrail rather than the aft handrail and my body had a sort of a sideward component whenever I pushed down on the QD. I not only tended to pitch my body down against the side of the adapter but also tended to roll off, and this made it slightly more difficult. Anyway, I did get the thing plugged up on the second try, and I used maybe 5 minutes doing this. The reason I wasted so much time was because I had to correlate my body position with John."

In the water immersion simulation the subject experienced similar difficulties with inadvertant activation of the connector and with his feet interacting the spacecraft exterior.

During the water immersion simulation the ERA subject also had difficulty in obtaining and maintaining a handhold on the smooth docking cone lip. Further, even though the mockup halfsection of the TDA was fairly rigid due to buoyancy the subject's motion continuously affected the mockup. The subject also had difficulty in operating the S-010 latches and in attaching the sections of the S-010 to his chestpack and velcro patch on his thigh. The astronaut had a similar experience during flight. Pilot Collins and Command Pilot Young stated in the postflight debriefing -

Collins - *"Igrabbed hold of the docking cone as near as I can recall, at about the two o'clock position. If you call the location of the notch in it, the 12 o'clock, I was to the right of that -- at about the two o'clock position and started crawling around. No, I must have been more about the four o'clock position, because I started crawling around at the docking cone counterclockwise, and the docking cone itself, a leading edge of the docking cone, which is very blunt, makes a very poor handhold in those pressure gloves. I had great difficulty in holding on. And, as a matter of fact, when I got over by the S-010 package and tried to stop my motion, my inertia, my lower body, kept me right on moving and my hand slipped and I fell off the Agena."*

In the first water immersion simulation run the Agena Target Vehicle was fixed mounted on the pool floor. The subject staged on the forward end in front of the docking bar guide. His initial efforts at T-17 and S-010 operation were impeded because the chest pack interacted the docking cone. The subject rolled over on his back to free the chest pack and grasped the edge of the docking cone. The subject moved around the lip of the cone by a sliding hand motion, taking care to retain a handhold at all times. The subject altered his position by exerting forces with his hands, using random handholds in the area between the docking cone and the Agena interface. This resulted in placing the subject in a position facing the velcro pad located on the Agena surface.

A second simulation run was performed to assess the factors involved when the Agena mockup was allowed to move in six degree of freedom motion. This was accomplished by suspending the Agena mockup above weights located on the pool floor. The mockup was connected to the weights by a three cable suspension. In this manner the effect of subject velocity at the time of contact was assessed. The subject was propelled toward the mockup at a low velocity from a separation distance of approximately three feet.

This attempt failed because the subject could not maintain a visual sighting of the mockup and consequently lost physical contact as he passed over the mockup. Momentary contact with the mockup caused significant motion perturbation to both the subject and the mockup. Since no handholds were provided further attempts at contact by the subject only added to the motion perturbation.

A second attempt at subject contact with a semi-free mockup was successful. The subject had determined proper orientation and hand position prior to the maneuver.

After successful initial contact the subject moved to the experiment area in a manner similar to that performed during the fixed mockup simulation run. Mockup perturbation was minimal during movement to the experiment area and was only visible when the subject attempted to maneuver over the lip of the docking cone. This mockup movement did not degrade the subjects performance. It is felt that the motion was not entirely representative of the free motion of the Agena in space due to the mockup configuration. However, the effect of semi-free mockup ac action in the water simulation aided in assessing similar effects in the true space environment.

Collins continued his description of the orbital performance in his debriefing -

> *Collins - "At any rate, I slowly worked my way around to the S-010 package and removed the nose fairing. If took me about three or four stabs to get both those buttons pushed. The button on the right, I think, I got the second time and the button on the left, I believe, I got the second time. And when they were both pushed in, I got my fingers down in that hole on top of the fairing and eased the fairing forward. The fairing came forward and then felt like it was locked in place. But when I gave it an upward component it did come off. And I was trying to do this very gently, because the fairing was connected to the main S-010 package by these two little wires, which are simply pins that would pull right out of the S-010 package. I very gingerly removed the nose fairing and without putting an pressure on the wires, I went back and grabbed a hold of the S-010 package itself and removed it. I held, from that time on, I held the S-010 firmly in my left hand and the wires held, and we got the nose cone back in that manner."*

While the simulation of the Gemini X umbilical was by no means a complete task line, several important conclusions were drawn.

(1) The several Gemini umbilical EVA tasks simulated (T-17, S-010 and the nitrogen disconnect) were adequately accomodated by water immersion techniques.

(2) Equipment carried on the suit exterior would have to be secured to prevent damage or loss.

(3) Body dynamics and motion characteristics were adequately simulated as long as the astronaut was restricted to motions on or near the surface of the spacecraft.

(4) The characteristics of certain of the mockups previously used in conjunction with zero gravity aircraft were insufficient to yield adequate information as to body-spacecraft interactions.

(5) Handholds must be provided to accommodate the tasks planned.

These results were substantially borne out by the astronaut's performance in space.

4.2 - GEMINI IX - The Gemini IX simulation was the first instance of astronaut participation at ERA. The GT-IX simulation run took place at the ERA facility after the preflight simulation of the Gemini X umbilical EVA tasks. The Gemini IX simulation allowed direct comparison of water immersion simulation performance with actual experience from space.

The mockup for the Gemini IX simulation consisted of a full scale section of the aft end of the equipment adapter with the AMU fixed in the center of the gold protective curtain. Two sets of foot restraints were attached. The actual foot stirrups were located in the proper activated position relative to the AMU. A second set of foot restraints, the "dutch shoes", were located 180° opposite the foot stirrup location. These latter foot restraints were a proposed concept for the GT-XI and XII flight that Astronaut Cernan was to evaluate at the end of the GT-IX simulation run. Figure 4-2 shows the Gemini IX mockup in the water simulation facility.

The following procedure was used in this and all subsequent simulation-training runs at ERA. After the mockup was placed in the water relative to operational and photographic constraints, initial runs by SCUBA (wet suit) equipped subjects and observers were made to assess potential simulation difficulties and deficiencies. Appropriate changes to the mockup and setup were made to yield maximum single-run simulation fidelity characteristics.

An ERA subject wearing a pressurized Gemini suit performed the total simulation run one or more times under astronaut (in situ) observation to familiarize the astronaut with the simulation technique and procedures and to serve as a final check on simulation equipment and time line fidelity.

In many instances the hardware supplied was not valid flight hardware. The mockups also were not 100% fidelity in that they represented only general mold line conformation to the spacecraft. Discrepancies were noted and discussed by observers and the astronaut and appropriate changes were made where required. Where the change obviously would not increase the information content of the run, no changes were made. As the program developed, mockups were continuously updated to assure the greatest validity in true space operation.

The Gemini IX task simulated at ERA comprised only the AMU donning task. Table IV summarizes the sequential steps simulated. As was stated earlier, the Gemini IX umbilical EVA of Astronaut Cernan was the first indication of potential difficulties of man's operation in space. Several aspects of the IX performance contributed to this:

(1) *Prior to the IX mission, no simulation technique existed which would give a true picture of the AMU donning portion of the task, particularly the weightless aspects of the tasks. The zero gravity aircraft simulated the task in a number of thirty second segments. This did not give a true picture of the cumulative task work-load. One gravity walkthroughs did not determine the work required to maintain body position while working and those due to the requirement to exert forces and torques without the aid of normal 1G traction.*

(2) *Up to the time of the mission, umbilical EVA was thought to be relatively easy due to the experience of Astronaut Col. E. White on Gemini IV.*

(3) *Minor hardware equipment malfunctions during the EVA contributed to accelerated heart rates. A garment tear in the inner layer suit contributed higher heat loads.*

(4) *The umbilical EVA was terminated due to visor fogging brought on by excessive work loads complicated by the suit problem.*

With this as a basis, a water immersion task simulation evaluation program was conducted using both the ERA subjects and Astronaut Cernan. The purpose of this EVA simulation was not primarily to solve the problems encountered by Astronaut Cernan. Rather, the purpose was to allow Astronaut Cernan to assess the simulation technique in the light of his recent space experience, in order to provide NASA with guidelines for the remaining Gemini umbilical EVA missions.

Three simulation runs of Gemini IX type tasks are discussed and compared in the following section. These are: (1) the postflight run by the Gemini IX astronaut, (2) a comparison run of the Gemini IX task by the ERA test subject, and (3) the preflight run of the initially scheduled Gemini XII task by Astronaut Aldrin. Comparison of these three runs yields direct correlation of the effectiveness of the various foot restraint modes used throughout the Gemini missions. Astronaut Cernan used the GT-IX foot stirrups, while the "Golden Slipper" foot restraints were used by Astronaut Aldrin. The ERA subject performed the AMU donning task both with and without foot restraints.

Much discussion has been forthcoming on the value, validity, and future use of foot restraints as a result of the outcome of the Gemini IX EVA. The determination of the exact value of the foot restraints requires an examination of conditions existing prior to water immersion simulation.

Three problems had been identified as responsible for the early termination of the umbilical EVA of GT-IX

(1) *lack of a valid simulation mode for long duration tasks*

(2) *improper body restraints*

(3) *ELSS capacity exceeded*

The astronaut stated that throughout his EVA, his feet continually floated away from the spacecraft and that he had to expend considerable energy maintaining body position. He also stated that these factors had not been reproduced during preflight simulation runs in the zero gravity research aircraft.

At the time of the postflight water immersion simulation of the GT-IX umbilical EVA, ERA specifically set about investigating this unrestrained motion phenomena to determine whether similar effects would be encountered during water immersion simulation runs. The NASA had at this time already planned and initiated future space experiments to determine the body motion effect and to circumvent body positioning difficulties. The GT-X pilot and subsequent EVA astronauts would try to reproduce the free-float tendencies experienced by the GT-IX pilot. Missions XI and XII would include redesigned foot restraints. Further, the primary emphasis of the GT-XII umbilical EVA would be an evaluation of restraints.

The postflight evaluation run of Gemini IX was performed by Astronaut Cernan at the ERA facility on 7/29/66 and lasted for approximately 3 hours. The AMU was mounted in the stowed position in the adapter well and the foot stirrups were in the activated position. The astronaut staged from the position in the flight line where he enters the adapter from the handrail and inserts his umbilical in the pigtail and handbar clips. Figure 4-3 shows the astronaut at this stage of the simulation. Table V details the results of the analysis of the film record of the water immersion simulation of GT-IX.

The total duration scheduled for the GT-IX umbilical EVA was 167 minutes, but it was terminated 39 minutes early due to the visor fogging problem mentioned earlier. Visor fogging occured at a point in the task line immediately after the lowering of the AMU controller arms. This task is shown in Figure 4-4 in the water immersion simulation. In the simulation, Astronaut Cernan performed the controller arm unstow tasks a number of times in order to compare the simulation with his space experience.

The unstow task required the astronaut to exert a large pushing force on the top of the controller arm to free the arms from a detent. The motion was to compress a relatively high force (approximately 25#/in.) spring approximately 1/2-1" in order to allow a blade shaped detent to move free of its retention slot. General mission requirements were *that the astronaut was instructed to maintain his stance in the foot stirrups shown in Figure 4-5 during the AMU donning sequence. This posture required the astronaut to simultaneously compress the controller arm and to bend the suit at the torso and at the arm. All these suit motions require large forces and induce high metabolic loads. The astronaut reported that the water immersion simulation mode adequately reproduced the major aspects of EVA performance. To provide a direct comparison of the effectiveness of the foot restraints, an evaluation of the ERA subject's performance without restraint aids and Astronaut Aldrin's performance of the original version of GT-XII with the molded foot restraints was made. Three criteria of comparison were used (1) direct time comparison from film analysis, (2) average limb motion from film analysis, and (3) subjective comments both from the subjects and the direct observers. Table VI shows the effect of the restraint mode on the subtasks comprising the AMU donning tasks. It is evident that, in general, the more restrained the individual the greater the duration of the task. . General analysis of the motions involved further indicate that for the AMU donning task that the greater the restraint the greater the energy required for suit flexure. This is attributed mainly to the rigidity of the space suit and the relative placement of the restraints and the work station.*

The natural angle of the upper torso and arms of the Gemini suit were fixed for optimum operation in a seated mode. While standing, the neutral position of the arms caused the optimum work level to correspond to a position approximately one foot below eye level. The AMU donning task required relatively high level force application in a region (+ 1.5) feet from this optimum work site. Therefore, a large portion of the tasks induced an added energy requirement for suit flexure. This is basically true whenever the position of operation is fixed relative to the worksite. Fixed work spaces impose a "psuedo" one gravity handicap on the task. Optimum operation in weightless environment allows the astronaut to freely position himself relative to the worksite and thus optimize the energy expenditure for each task. This is borne out by the qualitative evaluation of the AMU donning task without restraint aids presented in Table VII . This is not to say that the astronaut should work in a completely unrestrained condition. It appears that for most tasks the best combination of restraints are waist tethers to control gross motions to relative proximity of the worksite and portable handholds to permit the application of forces or torques.

Subsequent to Astronaut Aldrin's training for the GT-XII task (first version), NASA decided to reconfigure the tasks to comprehensively cover the broadest possible spectrum of EVA tasks. Table VIII shows the results of the analysis of the water immersion simulation of GT-XII (1). Analysis of the results of the simulation indicate that the astronaut could have properly and successfully completed the tasks as originally scheduled but that minor modifications to the restraint design should be accomplished if a similar task is scheduled for future missions.

4.3 - GEMINI XI - Water immersion simulation of the Gemini XI umbilical EVA was initiated at ERA on August 10, 1966. Due to the proximity of the flight astronaut participation was not planned.

Certain portions of the sequences were omitted in the simulation due to unavailability of representative flight hardware or because of the obvious limitations of the simulation medium. Previous experience had shown that tasks involving gross, relatively high velocity motions and excursions away from the spacecraft suffer serious degradation in the water simulation mode due to the drag-damping characteristics of the water. Rapid attitude excursions of the subject are limited by the preferred attitude characteristics previously discussed and by drag and planing effects. HHMU evaluation is representative of tasks not particularly suited to water immersion simulation.

The Gemini XI simulation marked the initiation of the use of the total Gemini mockup configuration. All simulation runs after Gemini XI utilized a quasi-complete spacecraft system configuration which conformed in moldline contour to the actual spacecraft configuration. The basic mockup configuration comprised a modified adapter end section from the Gemini IX simulation, a representative Gemini R/R section loaned by the Langley Research Center, NASA and a quarter section of the adapter surface. In later simulations a section of the Agena target vehicle was added to the mockup complement but was unavailable for the GT-XI runs.

A sequential time line was performed by the ERA subject wearing a G2-C version FPS. Portions of the time line which were incompatible with the simulation medium were omitted. Actual hardware was used where available. Where this hardware was not available, reasonable facsimili were built at ERA and made neutrally buoyant where time permitted.

The USAF, WPAFB supplied a working version of the D-16 experiment, the torqueless power tool. This was made neutrally buoyant by encapsulation in a transparent plastic cylinder and is shown in Figure 4-6. The encapsulation increased the external dimensions of the tool making it impossible to stow in the equipment stowage area provided in the reentry adapter wall, Figure 4-7. A second unit was used for the unstowing operation but was not made neutrally buoyant.

An initial simulation run indicated that a rescheduling of the sequential events would result in better utilization. Also, the astronaut had been required to carry excess hardware (cameras) to the adapter. Recommended changes were incorporated prior to the final simulation run. The purpose of the GT-XI simulation was to provide a complete pictorial record so that NASA personnel and the crew could review the umbilical time line. The results of the analysis of the film record of Gemini XI simulation is given in Table IX.

The Gemini XI umbilical was terminated early after approximately thirty-three minutes of hatch-open time. This early termination was attributed to two factors; (1) difficulties with the attachment of the extravehicular visor prior to EVA and (2) an unusually high expenditure of energy by the pilot during the Agena tether task. The astronaut also noted a continuous tendency to float up and out of the spacecraft at the beginning of the EVA.

The retrieval of the S-009 experiment and the handrail erection went smoothly. The first problem encountered was with the installation of the EVA motion picture camera. This difficulty was later attributed to a last minute change in the design and operation of the bracket. The camera had to be inserted in one orientation to permit a detent to mate with an antirotation slot in the receptacle. The astronaut had to exit the hatch to bring his body over and above the camera receptacle and exert a relatively high pushing force to install the camera. Figure 4-8 , is a picture showing the ERA subject installing the camera during the preflight simulation.

Astronaut Gordon then moved to the area of the Agena tether. He pushed off the hatch and the hatch holding device using a technique suggested by Astronaut Cernan, and moved to the docking bar, attempting first to grasp the RCS thrusters. His initial push off caused him to float up above the TDA. Command Pilot Conrad retrieved him by hauling him back with the umbilical. His second try at this movement was successful. Figure 4-9 is a pictorial sequence from the water simulation run of this segment of the time line.

Attaching the Agena tether involved an unusually high expenditure of energy, and the pilot became very fatigued and began breathing rapidly. Figure 4-10 is the astronaut's heart rate and respiration rate during the EVA. Measurements of similar parameters were not made during the simulation since the simulation involved only the ERA subject. Figure 4-11 is a flight film sequence showing activation of the Agena tether. The following comments by the command pilot and the pilot during the postflight debriefing describe the detailed performance.

> *Gordon - "Well, we did get it, and I tried to get myself in position on the spacecraft, as I had done before. I wanted to use my legs inside the docking cone to help wedge myself in there so that I could have both hands free. But, unfortunately, this was not the case. It didn't happen this way. I had to use my left hand and hang on to the handhold on the left side and do all the work and attaching this tether with my right hand. And this was a monumental task as far as I was concerned."*
>
> *Conrad - "Yes, now let's stop right there. I had watched you do this very task in the zero-g airplane. You could get in that zero-g airplane and whistle up to that thing and get yourself parked where you were completely astride it and pull yourself down, but you never could do that up there. You were off the*

thing, and you never got your legs as far forward in the TDA as you did in the zero-g airplane. It just wasn't quite the same. And there you were. I kept seeing you working away, having to hang on with your left hand."

Gordon - "Tethering was difficult; it was so hard to maintain my position and work on this thing, that I let my feet float up and out of there and use one of the handholds and one hand on the clamp. I had an awful lot of trouble screwing this clamp down. Every time I tried to turn it, it would swivel on the docking bar."

Gordon - "Anyhow, I finally got the clamp on to my satisfaction. The tether was in place. There was one test remaining to do up there, and that was to install the mirror. I took one tug at the cover that was over that mirror, and it didn't give an inch. I just gave it up and said forget it. I came back to the hatch."

Conrad - "That was quite a job getting you back to the hatch. You asked me to do something a couple of times. I gave you a very light tug and you started to take off up and away from the hatch."

Gordon - "Well, we did get back to the hatch, and by this time I was pretty exhausted. We stood there for a long time trying to catch up with everything, and the only thing that was really wrong was that I was having trouble with my right eye. This was merely a matter of sweat in my eye, and I was having trouble seeing out of it. It was actual sweat, and it was stinging my eye. I was completely exhausted at the time. I wanted to get back to that adapter very badly for the nightside pass, but we talked about this and made the decision to ingress rather than leave me out there for the nightside pass."

Figure 4-12 is a picture of the ERA subject performing the Agena tether task during the simulation. The ERA subject performed the Agena tether task in a manner completely different from the pilot. The ERA subject utilized the advantages of operation in a weightless environment to position himself in an optimum manner relative to the worksite and performed the task while maintaining a single handhold. A better method might have included the waist tether restraint technique which would have allowed the subject to use both hands. No undue effort was noted during the simulated performance of this task. The combination of excessive sweat buildup by the astronaut and the apparent fatigue caused the command pilot to terminate the EVA.

All other assigned tasks were accomplished without undue difficulty in the simulation with the exception of the D-16 experiment. The D-16 experiment hardware is shown in Figure 4-13. The subject was required to evaluate a combination of restrained and unrestrained operations utilizing a torqueless power tool (SPT) to establish man's *capability to perform controlled maintenance tasks in place. The initial evaluation was scheduled for the GT-VIII umbilical EVA, but was not accomplished due to the early termination of the mission. The D-16 experiment was the subject of extensive study and simulation by the USAF-WPAFB.*

Difficulties were encountered in the water simulation due to (1) the location of the torque panel relative to the restraints, (2) knee tethers activation, and (3) the excessive force requirements of the (SPT) trigger mechanism. Figure 4-14 is a sequence showing the D-16 task during the water immersion simulation. Similar difficulties did not occur in the simulation of the D-16 in the zero gravity aircraft. This difference is probably due to the relatively low fidelity of the hardware in the water simulation. The short duration of the zero gravity parabola, however, probably did not show the difficulties resulting from continuous application of force on the trigger and due to body position maintenance.

The results of the Gemini XI mission performance emphasized the need for more extensive simulation by water immersion techniques to develop flight hardware configurations. Further, it became obvious that astronaut training in the water simulation mode would greatly benefit mission performance. With this in mind, the NASA scheduled Astronaut Aldrin's participation in the water immersion simulation of the initial version of the GT-XII umbilical EVA. Details of the simulation effort of the GT-XII, version 1, were included in the section dealing with the GT-IX simulation due to task similarity.

TASK	SUBTASK	TIME INTERVAL (Seconds)	COMMENTS
T-17	Initial body positioning evaluation	33.4	Subject attempts to find correct handhold positions for approach to S-10 area on Agena.
	Movement	20.8	Subject travels along circumference of TDA, retaining contact with left hand.
	Positioning prior to T-17 placement	15.0	T-17 lost due to interaction with mockup.
	T-17 placement	66.6	Subject recovers T-17 with right hand and places experiment on Agena velcro retention patch; Left hand maintaining body position during this subtask.
	Manual deployment of T-17 panels	5.0	Subject unfolds experiment manually using right hand to maintain body position. Subject secures open panels to velcro (spring loaded mechanism for automatic unfolding panels not operative) Subject inadvertantly touches face of T-17 while attempting body positioning.
S-10	Positioning prior to S-10 retrieval	16.6	Subject maintains handhold on lip of docking cone throughout this movement.
	S-10 fairing removal	58.3	Far ing velcroed to ELSS. Subject uses left hand to maintain contact with Agena.
	S-10 experiment retrieval	29.1	S-10 removed with left hand and velcroed to ELSS. Interaction with T-17 and left side of subject's body almost frees experiment from its velcroed position.
HHMU-N_2-QD Activation	Movement - s/c along hand-rail to Quick Disconnect Panel	6.2	Subject pivots on handrail (180°) at QD panel.
	Positioning	20.8	Subject transfers QD hose through aft section of handrail (threading operation).
	QD connection	22.9	
	N_2 valve activated	29.2	Subject examines QD and hose momentarily before activation.

TABLE III Continued

TASK	SUBTASK	TIME INTERVAL (Seconds)	COMMENTS
HHMU-N_2-QD Activation (Cont)	Movement - QD panel along handrail to s/c	37.5	
HHMU-N_2-QD Deactivation	Movement - s/c along handrail to QD panel	28.1	Subject again pivots 180° on handrail.
	N_2 valve shutoff and QD disconnection	11.4	Subject uses left hand for both subtasks.
	Movement - QD panel along handrail toward s/c	16.7	Subject transfer QD hose to left hand before moving down handrail.
	Positioning	12.5	Subject transfers QD hose back through aft section of handrail (unthreading operation).
	Movement along handrail to s/c continued	41.7	

1. Move to adapter pigtail along adapter handrail
2. Insert umbilical into adapter guard
3. Move to donning station - stand on foot bar facing AMU
4. Pull umbilical taut and insert in hand bar clip
5. Unstow and position mirrors
6. Open penlights - actuate and attaoh lights to handrail with velcro
7. Connect black tether jumper hook to AMU tether ring. Unstow tether bag and connect both orange AMU tether hooks to ring on umbilical tether
8. Inspect AMU
9. Inspect battery cases
10. Verify RCS shut-off handles stowed
11. Unstow attitude controller arm and check attitude controller
12. Extend and lower controller arm to full down position
13. Unstow translation controller arm and check translation controller
14. Extend and lower controller arm to full down position
15. Unstow restraint harness, oxygen hose and electrical umbilical
16. Attach the following items in order to velcro on controller arms
    (a) oxygen hose
    (b) restraint harness
    (c) electrical umbilical
17. Read N_2 pressure
18. Open N_2 valve
19. Open O_2 valve
20. Read O_2 and N_2 pressures
21. Mode selector switch-manual
22. Verify vox switch-vox
23. Release nozzle extensions
24. Main power switch-on
25. H_2O_2 T/M selector switch-backpack up
26. Turn left 180° and don AMU
27. Position tether to avoid entanglement
28. Verify s/c PWR light goes off
29. Verify availability of AMU electrical umbilical and change-over from s/c
30. Test warning lights and audio tone
31. Read H_2O_2 quantity
32. Connect and tighten restraint

TABLE IV

GEMINI IX WATER IMMERSION TASK SEQUENCE

TASK	SUBTASK	TIME INTERVAL (Seconds)	COMMENTS
Positioning/Restraint	*Pull umbilical taut and insert in handbar clip*	5.5	
Work Station Preparation	*Unstow left mirror*	48.4	
Positioning/Restraint	*Position from left to right side of work station to deploy right mirror*	7.8	
Work Station Preparation	*Unstow right mirror*	12.5	
Positioning/Restraint	*Position back into foot restraints after mirror task*	22.2	
Work Station Preparation	*Unstow penlights*	41.6	
Communications	———	11.8	*Instructions from C.C.*
Positioning/Restraint	*Repositioning umbilical in clip*	9.3	
Positioning/Restraint	*Repositioning feet in stirrups*	8.4	
Connect Black Tether Jumper Hook to AMU Tether Ring	———	25.6	
Communications	———	8.7	
Unstow Tether Bag	———	23.0	
Connect Both Orange AMU Tether Hooks to Ring on Umbilical Tether	———	86.1	
Positioning/Restraint	*Reposition tether bag*	13.1	
Inspect AMU and Battery Cases	———	38.1	
Verify RCS Shut Off Handles Stowed	———	33.4	
Positioning/Restraint	*Reposition feet in stirrups*	17.0	

TASK	SUBTASK	TIME INTERVAL (Seconds)	COMMENTS
Unstow Attitude Controller Arm and Check Attitude Controller	———	27.5	Extend and lower controller arm to full down position
Communications	———	6.6	
Unstow Translation Controller Arm and Check Translation Controller	———	66.4	Extend and lower controller arm to full down position
Communications	———	6.9	
Unstow and Attach O_2 Hose to Velcro on Controller Arm	———	31.3	
Positioning/Restraint	Body positioning of feet in restraints	36.5	Pilot repositions his feet in restraints because his body movements degrade his foot restraint position during each task that involves reaching or bending
Unstow and Attach Electrical Umbilical to Velcro on Controller Arm	———	24.5	
Communications	———	25.0	Pilot also appears to be resting here.
Positioning/Restraint	Body positioning	6.9	Pilot removes feet from foot stirrups prior to maneuvering over to read N_2 pressure.
Read N_2 Pressure	Maneuver to left side of AMU	8.4	
Positioning/Restraint	Body positioning	10.8	Pilot returns to foot stirrups after reading N_2 pressure
Unscheduled	———	3.6	Pilot pauses to remove debris from front of his work area (floating velcro strips)
Positioning/Restraint	———	6.9	Pilot readjusts penlight on left hand bar
Open N_2 Valve	Pilot reaches around left side of AMU	15.6	Feet in restraints at beginning of this task but during task both feet come free of restraints
Open O_2 Valve	———	53.2	

TASK	SUBTASK	TIME INTERVAL (Seconds)	COMMENTS
Read O_2 and N_2 Pressures	—	14.0	
Positioning/Restraint	Position back into stirrups	16.2	
Switch Mode Selector Switch to Manual and Verify Vox Switch on Vox	—	22.5	
Positioning/Restraint	Positioning on handbars and regaining feet position in restraints	23.3	
Release Nozzle Extensions	—	15.1	
Positioning/Restraint	Repositioning feet in restraints	15.7	
Communications	—	18.8	
N_2O_2 T/M Selector Switch Switched to Backpack Position	—	2.1	
Unscheduled	—	184.4	Pilot pauses for an air bottle change (surface)
Work Station Preparation	Equipment positioning	9.1	Pilot positions his umbilical and mirror prior to 180° turn into AMU (safety precaution)
Turn Left 180°	—	26.9	
Don AMU	—	18.1	Pilot backs into backpack
Positioning/Restraint		46.5	Pilot positions his mirrors to check his position in AMU
Verify Availibility of AMU Electrical Umbilical and Change Over From Spacecraft to AMU Power	—	120.8	
Connect and Tighten Restraint	—	37.7	Decision made at this point in GT-9 flight to abort task

TABLE VI

THE EFFECT OF RESTRAINTS ON AMU DONNING

Subtask	Subtask Time : second		
	Foot Restraints	Foot Stirrups	No Restraints
Umbilical In Clip	63.9	5.5	87.0
Unstow & Position Mirrors	132.5	68.7	66.0
Penlights	59.4	41.6	43.4
Connect Tether Jumper	24.5	25.6	25.0
Unstow Tether Bag	106.5	117.8	87.0
AMU Inspection	118.8	71.5	35.0
Unstow Left Controller	29.5	27.5	18.0
Unstow Right Controller	72.3	73.3	49.0
Unstow & Velcro Electrical & O_2 Connectors	77.6	55.8	21.0
180° Turn	274.6	73.4	120.0
Connect - Tighten Restraints	103.7	158.5	148.6

TABLE VII

QUALITATIVE EVALUATION OF THE EFFECT OF FOOT RESTRAINTS ON THE AMU DONNING TASK

SUBTASK	EFFECT OF FOOT RESTRAINTS
UMBILICAL IN CLIP	+
UNSTOW LEFT MIRROR	−
REPOSITION	−
UNSTOW RIGHT MIRROR	−
UNSTOW PENLIGHTS	−
UNSTOW TETHER BAG	−
TETHER HOOK ACTIVATION	+
A M U INSPECTION	−
UNSTOW RIGHT ARM	+
UNSTOW LEFT ARM	+
OPEN N_2 AND O_2 VALVES	−
READ PRESSURE GAGES	−
UNSTOW RESTRAINT BELT	+
TURNAROUND	−

+ AIDED − DETERED

TABLE VIII GEMINI XII (1) WATER SIMULATION DATA ANALYSIS

ENVIRONMENTAL RESEARCH ASSOCIATES

TASK	SUBTASK	TIME INTERVAL (Seconds)	COMMENTS
Install EVA Camera in Adapter	*1. Secure from cockpit*	36.6	
	2. Mount camera	166.9	
Move To Adapter	*1. Egress hatch*	9.6	
	2. Move along handrail to pigtail	43.1	
	3. Insert umbilical in pigtail	32.5	
Retrieve and Replace EVA Camera	*1. Egress hatch*	9.6	
	2. Remove camera from adapter socket	1.7	
	3. Place in cockpit	15.5	
	4. Film load	60.0	
	5. Return to adapter and replace camera	35.6	
HHMU QD Connect	*1. Egress hatch*	9.6	
	2. Secure line and move along adapter handrail	6.9	
	3. Position QD for connection	7.6	
	4. Connect QD	4.8	

TASK	SUBTASK	TIME INTERVAL (Seconds)	COMMENTS
AMU Donning-XII Configuration	1. Start with feet in stirrups to attach umbilical to left handbar	63.9	
	2. Unstow and position mirrors	132.5	
	3. Unstow penlights and velcro to handbars	59.4	
	4. Connect black tether hook to AMU tether ring	24.5	
	5. Unstow tether bag and connect tether hook to umbilical	106.5	
	6. Velcro tether bag to left handbar	6.7	
	7. Inspect AMU	62.9	
	8. Inspect RCS handles	55.9	
	9. Unstow left controller arm	29.5	
	10. Unstow right controller arm	72.3	
	11. Unstow and velcro oxygyn hose	34.1	
	12. Unstow and velcro restraint harness	55.6	
	13. Unstow and velcro electrical connector	43.5	
	14. Open nitrogen valve	18.1	

TASK	SUBTASK	TIME INTERVAL (Seconds)	COMMENTS
AMU Donning - XII Configuration (cont)	15. Remove and discard oxygen valve tie-down	28.1	
	16. Open oxygen valve	28.7	
	17. Actuate MODE, VOX switches	24.0	
	18. Release thruster nozzles	27.0	
	19. Turn 180° and back into AMU	219.0	
	20. Attach electrical connector, oxygen hose and restraint harness	103.7	
Agena - Spacecraft Tether Connection	1. Egress hatch and position EVA camera	51.1	
	2. Translate along spacecraft to docking bar	61.6	
	3. Grasp Agena tether	31.0	
	4. Clamp tether to docking bar	92.8	
	5. Mount mirror on docking bar	40.3	

TASK	SUBTASK	TIME INTERVAL (Seconds)	COMMENTS
Sequence 1	1. Standing in hatch	224.6	
	2. Position propellant line back to propellant valve Route under handrail	84.2	Subject drifts out of spacecraft during this maneuver
	3. Install EV camera in adapter mount. Face camera forward	264.2	Subject has extreme difficulty mounting camera
	4. Mount Hasselblad on ELSS	75.8	
Sequence 2	1. Move to spacecraft nose	10.9	Subject is out of spacecraft hatch when he begins translating forward Film segment ends as pilot reaches spacecraft nose. Possible time error.
	2. Unstow spacecraft end of Agena tether	——	Subtask omitted in simulation due to low mockup fidelity
	3. Loop end over docking bar	——	"
	4. Unstow tether clamp and install on docking bar	——	"
	5. Tighten clamp	——	"
	6. Remove and jettison clamp handle	——	"
	7. Install docking bar mirror	27.9	Subject comments "No problem" installing mirror
	8. Return to cockpit	39.2	
Sequence 3	1. Remove EVA camera for film change	21.7	
	2. Remount EVA camera facing D-16 area	59.6	
	3. Plug in HHMU propellant fitting	25.8	

TASK	SUBTASK	TIME INTERVAL (Seconds)	COMMENTS
Sequence 4	1. Perform D-16 Experiment		
	A. Grasp handrail and position self for knee tether attachment	11.7	Hasselblad carried to D-16 area because of low fidelity mockup characteristics. Unit could not be detached from chest pack.
	B. Attach rt. knee tether to handrail	19.8	
	C. Grasp tool box handle, release lock and extend toolbox until positive lock is engaged		
	D. Open tool box, extend power tool handle, check it. sw to forward and tool in impact mode	48.7	
	E. Grasp power tool, tighten instrumented bolt for five (5) seconds	12.9	
	F. Unscrew in succession four (4) worksite bolts	61.6	
	G. Stow power tool, turn over worksite plate and hand-start three (3) bolts	85.0	Stowage clip not evaluated because of size of neutrally buoyant gun. Pilot comments " cannot see clip when knee tethered"
	H. Unstow power tool, reverse sw and tighten bolts	40.0	Subject comments "trigger force way too high... hand cramps due to force required."

TASK	SUBTASK	TIME INTERVAL (Seconds)	COMMENTS
Sequence 4 (cont)	I. Stow power tool on lid and remove hand tool	—	Subtask omitted in simulation. Power tool could not be stowed because of size requirements for neutral buoyancy.
	J. Tighten instrumented bolt for five (5) seconds and then loosen bolt	—	Subtask omitted in simulation.
	K. Stow hand tool in tool box	—	"
	L. Detach knee tether from handrail	53.3	
	M. Remove power tool, check it on, and tool in impact mode	4.29	Subject stops test during this subtask because of excessive work loads and overall inability to complete task due to low mockup fidelity (negative buoyancy of power tool).
	2. Remove EVA camera for film change	—	Subtask omitted in simulation
	3. Remount EVA camera facing aft	95.8	
	4. Evaluate handrails	68.7	
	5. Remove EVA camera for film change	—	Subtask omitted in simulation
	6. Remount EVA camera facing forward	—	"
	7. Move to adapter	9.6	
Sequence 5	1. Insert umbilical into adapter guard	14.6	
	2. Photograph adapter	36.9	Subject uses pigtail for body positioning

TASK	SUBTASK	TIME INTERVAL (Seconds)	COMMENTS
Sequence 5 (cont)	3. Clear adapter of debris	—	Subtask omitted in simulation.
	4. Attach restraint system	10.4	Subject unable to fully evaluate foot restraints due to improper fit (under size restraints).
	5. Open tunnel door and velcro in place	26.3	
	6. Unstow HHMU N_2 line	7.1	
	7. Connect HHMU to N_2 line	35.0	
	8. Unstow HHMU and velcro to ELSS	16.7	
	9. Attach camera lanyard to ELSS ring	—	Subtask omitted in simulation
	10. Remove camera pip-pin	—	"
	11. Unstow Apollo cameras and velcro to ELSS	94.2	
	12. Close tunnel door	42.1	Revelcro curtain
	13. Remove umbilical from guide	4.8	Subject comments that mirror was used to advantage in checking chestpack, umbilical and feet.
	14. Open N_2 valve on adapter	2.9	
Sequence 6	1. Move to cockpit	16.9	
	2. Hand cameras from ELSS	167.9	
	3. Mount retro adapter camera facing forward	34.1	

TABLE IX Cont'd.

TASK	SUBTASK	TIME INTERVAL (Seconds)	COMMENTS
Sequence 7	1. Move to nose of s/c	40.7	
	2. Jettison docking bar mirror	5.1	
Sequence 8	1. Return to adapter	97.9	
	2. Turn off "N_2" shut-off valve	2.9	
	3. Bleed off propellant in HHMU with short thrust while holding on to the adapter handrails	14.4	
	4. Unplug the HHMU propellant fitting	2.0	
	5. Move toward hatch	41.0	
	6. Retrieve EV camera and hand to cmd. pilot (disconnect electrical and control cable from camera first)	18.2	End of film

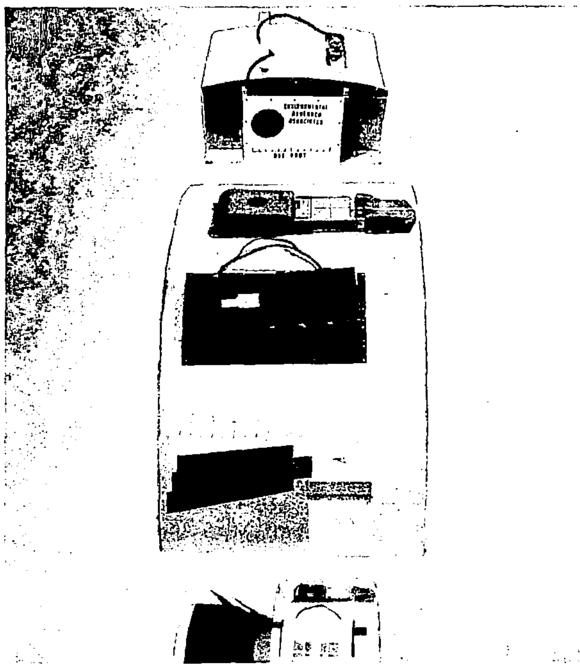


Figure 4-1 GEMINI X MOCKUP CONFIGURATION

Figure 4-2 GEMINI IX MOCKUP CONFIGURATION

Figure 4-3 ASTRONAUT CERNAN AT UMBILICAL PIGTAIL AREA

Figure 4-4 ASTRONAUT CERNAN UNSTOWING AMU CONTROLLER ARMS

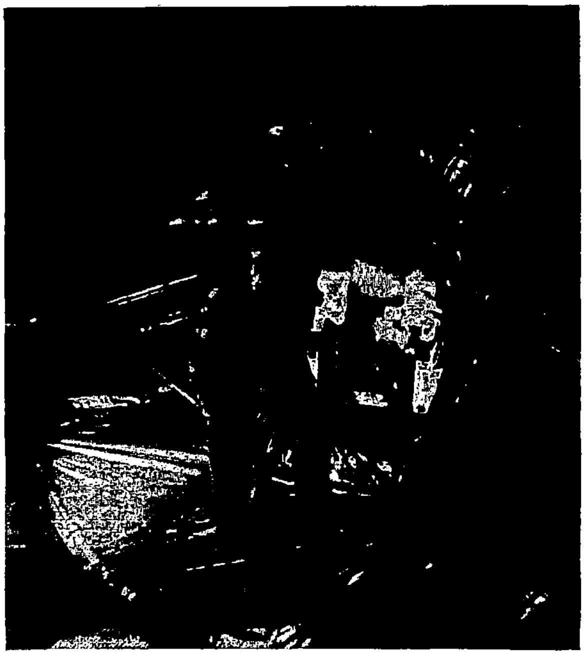


Figure 4-5 ASTRONAUT IN FOOT STIRRUP RESTRAINT SYSTEM

Figure 4-6 SUBJECT USING NEUTRALLY BUOYANT TORQUELESS POWER TOOL

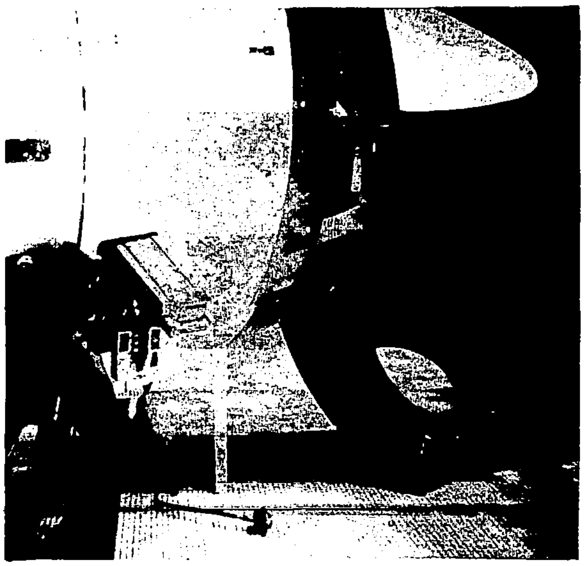


Figure 4-7 D-16 EXPERIMENT STOWAGE AREA

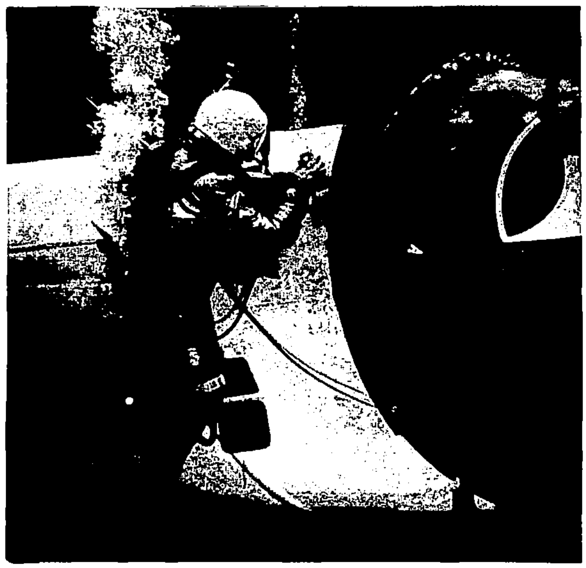


Figure 4-8 RETRO ADAPTER CAMERA INSTALLATION

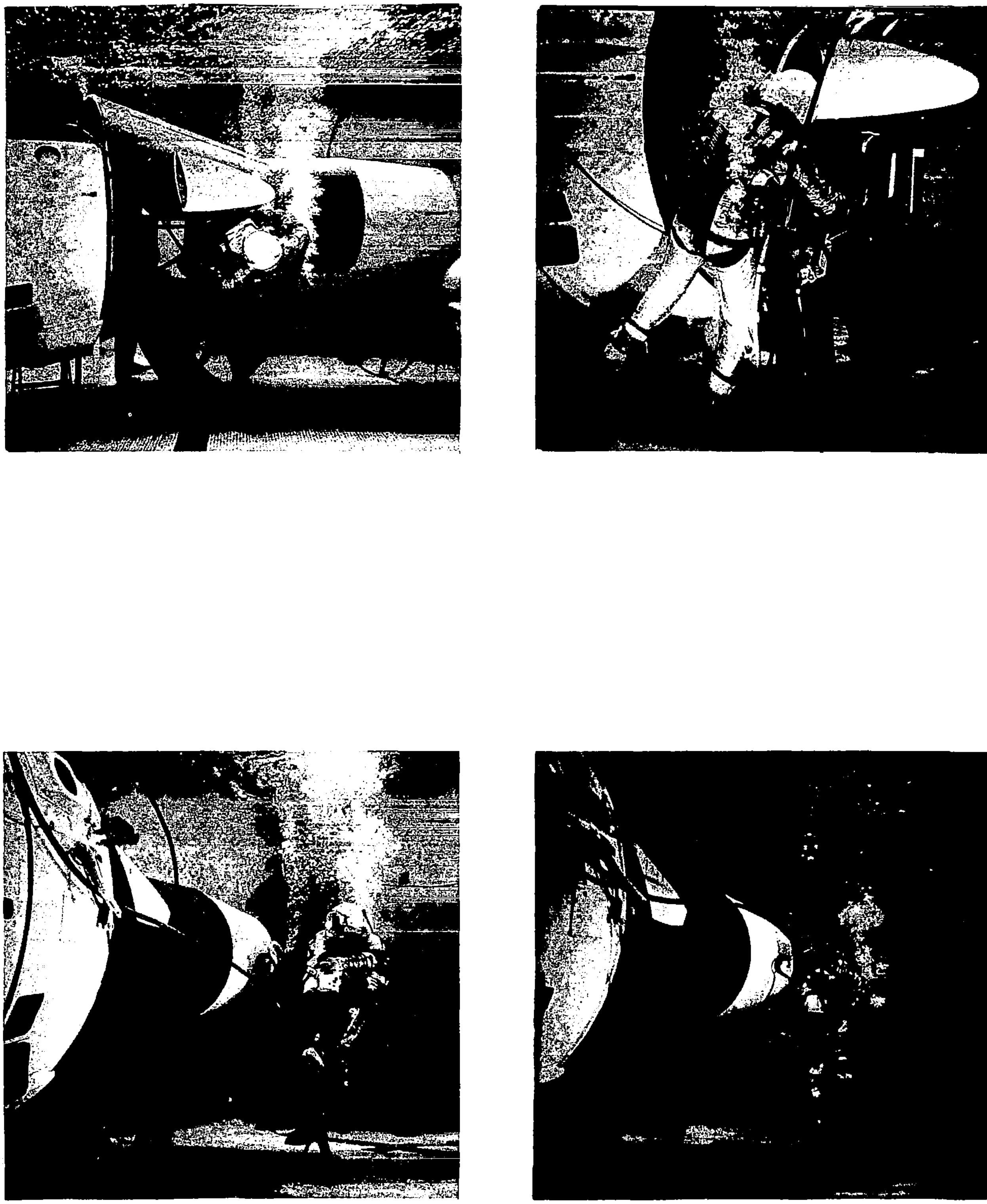


Figure 4-9 MOVEMENT SEQUENCE FROM SPACECRAFT HATCH TO AGENA

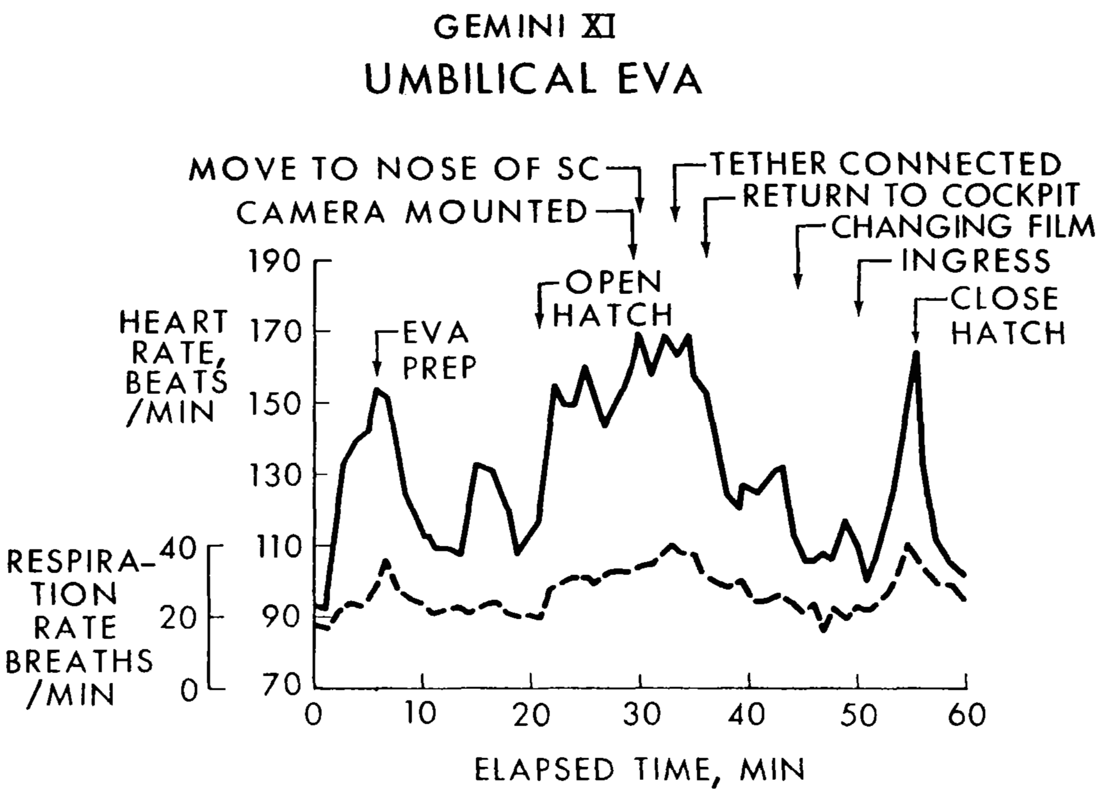


Figure 4-10 GEMINI XI HEART AND RESPIRATION RATE FOR THE ORBITAL EVA

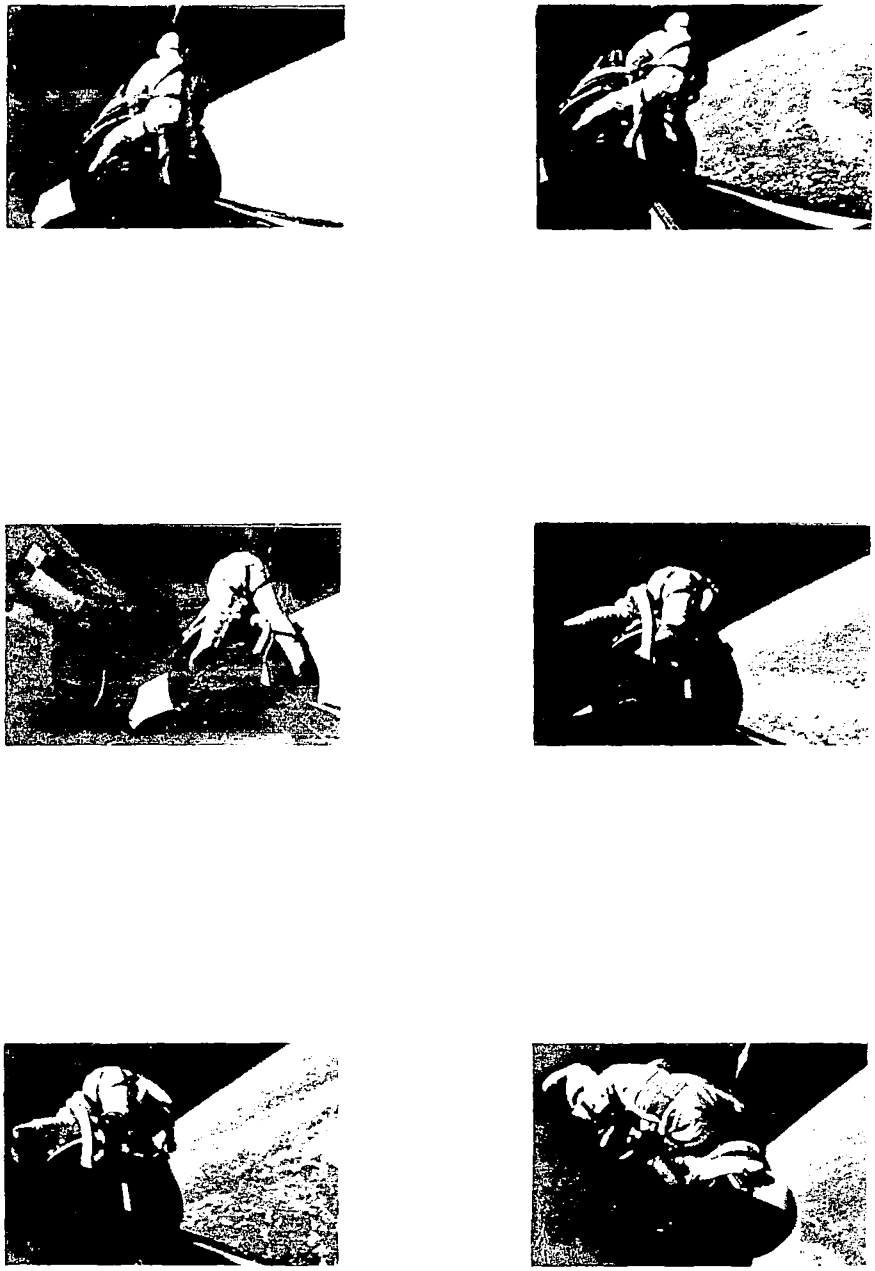


Figure 4-11 AGENA TETHER TASK IN ORBIT

Figure 4-12 SIMULATED AGENA TETHER TASK

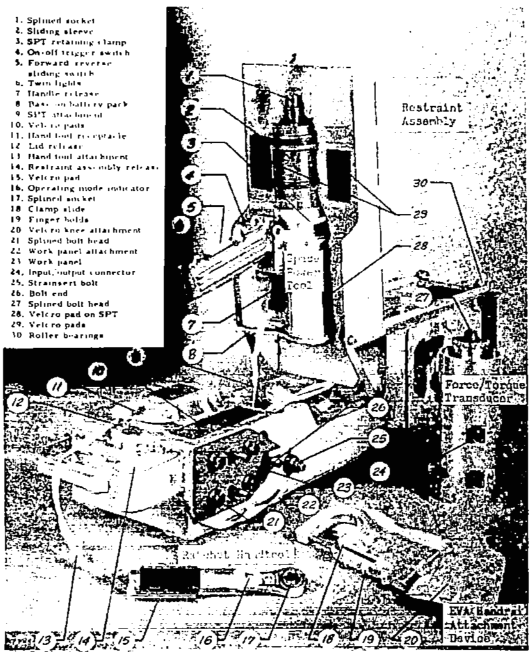


Figure 4-13 D-16 EXPERIMENT HARDWARE

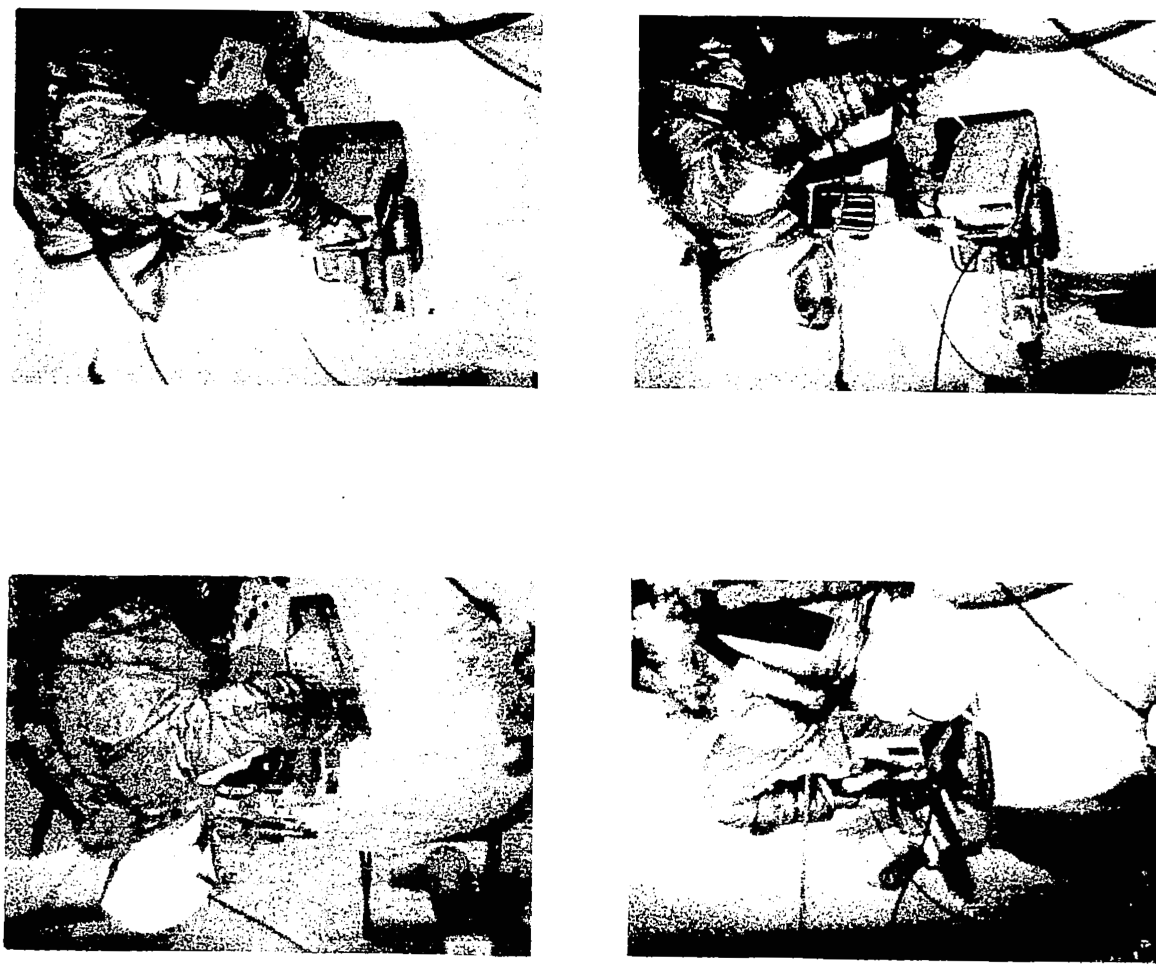


Figure 4-14 WATER SIMULATION OF D-16 EXPERIMENT

5.0-GEMINI XII

5.1 GENERAL

Gemini XII Orbital Mission Data - Data received from the standup and umbilical EVA periods of the Gemini XII flight include a transcript of the continuous onboard voice record and ten separate film sequences totalling approximately 16.5 minutes out of the one hundred twenty six minutes of umbilical EVA. This includes a 1.5 minute segment from the first standup EVA. There was no film coverage of work in the Adapter Section due to the failure of the portable camera. Consequently, all flight film relates to work on the spacecraft nose or at the Agena work station.

The onboard voice record, therefore, forms the only complete record of the GT-XII umbilical EVA. The only dificiencies in this record are due to time losses related to tape changes. Where possible, the flight film was compared with the voice transcript and these tape change intervals were determined.

The first iteration of the time line from the voice record of the flight was made from the transcript of the original onboard tapes. This was supplemented by analysis of the actual onboard tapes by ERA personnel. Analysis of the tapes in conjunction with continuous comparison of the voice tapes from the preflight water immersion simulation made it possible to fill in all time line "gaps".

The lack of continuous flight film and the original discrepancies in the flight voice transcript, made it necessary to use the preflight simulation as the base line of information from which to construct the first iteration flight time line. This analysis required a complete understanding of the movement and activities of the pilot during the simulations in order to visualize consistent performance in space. Applying this knowledge to the voice record and the film sequences from space, an overall picture of the actual umbilical EVA was constructed. Information from the two complete preflight simulation runs and from the partial postflight evaluation run aided immeasurably in the rationalization of discrepancies between the original iterations of flight and preflight and basic flight plan data.

Although a flight plan was used to coordinate the EVA work and rest periods during the preflight simulation tasks, the actual written plan did not serve as the basis for the time line comparisons. In effect, the entire final preflight simulation time line became the flight plan.

Flight Film Sequences - Although the visual quality of the GT-XII in-flight films was excellent, the perspective from which the film was taken in combination with the shadowing effects in space made detailed analysis of the flight film very difficult. In many instances critical task element took place completely in shadow, therefore making detailed visual analysis impossible. Analysis of specific body movements, especially for the arm and hands is not possible in at least 50% of the film. Even gross task identification proved difficult in some parts of the film, and was resolved by repeated viewing and comparison with similar preflight simulation films. Detailed comparison of individual tasks were, however, made on a frame by frame basis. The handrail erection is the most readily identified sequence. This sequence was not part of the umbilical EVA but was performed in a prior segment of the standup EVA. The second sequence, movement from the hatch area to the spacecraft nose and TDA interface, is also easily identified and analyzed. Subsequent task sequences can only be identified when a thorough acquaintance with the particular tasks is obtained. A second movement sequence, from the spacecraft hatch to the Agena work station (after adapter work session), is the only other readily identifiable sequence.

It should be noted that the camera position in space does not correspond with camera positions in the water or aircraft simulations. This fact contributes to the difficulty of direct comparison of the flight film tasks. Water immersion simulation films take advantage of optimum camera location for task analysis e.g., perpendicular to the spacecraft longitudinal axis. The portable EVA camera was located on a semi-fixed connector on the spacecraft retro-adapter section near the retro separation plane during the flight. This position could be readily reached by the pilot standing in the spacecraft hatch. The camera was aligned parallel with the longitudinal axis of the spacecraft allowing coverage of astronaut movement forward of the retro-adapter. Thus the basic difference is a 90° axis variation in camera positions between the water and space films. Also, for the water immersion simulation the camera is, in effect, looking down on the primary vehicle working areas from above the astronaut. By rotating the axis of perspective it was determined that body positions and movements in the simulation and in the actual flight corresponded very closely.

The initial movement from the spacecraft hatch along the portable handrail is an example of the similarity of motion between the space and water. Astronaut Aldrin performed a 180° turnaround on the handrail at the end of this movement. The flight film shows this turnaround to be in the opposite direction. When comparing the sequences from beginning to end of this initial translation, the movements appear to be almost identical in both time and body position. The water simulation turnaround made in the opposite direction appears as a mirror image of the actual flight turnaround. Figure 5-1 , a comparative sequence of the flight, water, and aircraft modes, demonstrates in greater detail the similarity in these movement sequences.

The major advantage derived from analysis of the film was the capability to compare the kinematics of the tasks with similar film records from the water immersion simulation. This comparison had aided in determining the correlation of water immersion simulation to the space performance.

Water Simulation - Prior to the Gemini XII mission water immersion simulation runs of the umbilical EVA tasks were performed at the Environmental Research Associates water simulation facility. The purposes of this simulation were: (1) to provide the EVA astronaut with a continuous real time training and (2) to organize and validate the final flight time line plan.

A continuous film and voice record was made of the last two preflight simulation runs. These final runs, subsequently referred to as Preflight I and Preflight II, were intended to be accurate rehearsals of the actual orbital EVA mission plan. After the Gemini XII mission, Astronaut Aldrin returned to ERA to perform a postflight evaluation of his EVA. Continuous film and voice records were made of this postflight run. The postflight evaluation run permitted the astronaut to investigate certain of the tasks in more detail than was allowed in space due to time constraints. Further, the astronaut evaluated several other closely related tasks which were not included in the GT-XII task line.

Although complete film and voice records were made on the Gemini XII preflight water immersion simulations, the films were edited prior to analysis. The loss of this edited portion complicated the film analysis and comparison. To reconstruct the complete time line, the voice transcript was compared to the film in order to identify the areas where film editing occurred. Tape change intervals did not affect this time line comparison since they did not normally coincide with film breaks.

Table X details the results of this preflight film-voice comparison. In this final iteration all legitimately identified time losses are included, and suspected time discrepancies are noted.

At times the astronaut's body position restricted view of his hands while working on a work station task. No serious problems in task interpretation were encountered during film analysis, however. Body/camera position conflicts mentioned above degraded the visual analysis of the "fine" hand movements and operations associated with the work station tasks. A synchronized voice transcript was used to interpret questionable areas.

Task performance does not precisely coincide with its verbal description. This was true throughout the GT-XII preflight simulations. Prime examples were the scheduled rest periods, wherein the astronaut would complete previous work tasks while commenting that he was resting. Because of this, film and voice time lines were constructed independently. The time variations between film and voice data in the *successive iterations, in general, support the rationale for data separation for initial iterations. Since the film was used as the true indicator of task time duration, discrepancies were reconciled in the final iteration time line with the data from the voice record serving mainly to provide continuity and fine level details.*

Figure 5-2 is a continuous pictorial sequence of the simulation time line including the handrail erection sequence of the EVA. This task was included in the water immersion simulation to serve as a standardized reference point and to provide an extra measure of practice for the astronaut.

In order that a high fidelity simulation be maintained, the handrail erection task was performed separate from the umbilical EVA time line. The pilot, standing in the hatch, deployed the handrail, marking the start and finish of this task on the voice tape. At the end of this task the command pilot initiated the start of the umbilical EVA time line. The umbilical EVA simulation commenced with the standup familiarization task.

Aircraft Zero Gravity Simulation - A limited portion of the work performed during aircraft zero gravity simulation program on the Gemini XII umbilical EVA has been supplied to ERA by NASA-MSC for purposes of cross-correlation of simulation mode. These simulations were very useful in determining the fine hand task details such as the hook and ring connections, the waist tether connections, and operations involving velcro handholds and pip pins. The preflight redesign of the pip pins serves as a good example of the utility of the zero gravity aircraft simulation. Prior to aircraft evaluation the pip pins, Figure 5-3 were free to rotate in the sockets. The aircraft observers determined that if the pip pins were allowed to rotate freely, serious interactions with free tethers could occur. The update version employed an anti-rotation pip pin design. Comparison of the available results of the aircraft simulation with water immersion and space performance is made as applicable.

General Configuration of the Umbilical EVA - The stated purpose of the tasks comprising the Gemini XII umbilical EVA was to determine the effectiveness of various restraint modes on EVA performance. The specific nature of the tasks and the restraints related to future missions configurations such as AAP. Since Gemini XII signified a temporary halt to EVA experimentation, the intent of the EVA was to yield answers to a broad as possible spectrum of representative future EVA tasks.

Figure 5-4 is a functional flow diagram of the major task events of the Gemini XII umbilical EVA. Although there were minor variations between the preflight simulation and the flight performance the major task sequence remained unchanged. Water immersion simulation was instituted to quantitatively determine the time line, to assess the levels of energy expenditure required to perform the time line and to specify the duration and frequency of rest periods in order to maintain energy expenditures at acceptable levels.

The initial task performed was standup familiarization. This task was designed to further evaluate the free float tendencies experienced on GT-IX and to prepare the astronaut for the umbilical EVA. Information from previous EVA's suggested that a familiarization period having minimum work levels could better introduce the astronaut to his new environment. The astronaut was also to evaluate the cooling effect of the ELSS at this time. The astronaut was then required to install and activate a 16 mm motion picture camera on the retro-adapter prior to the Agena tether task. Several attachment modes would be evaluated; (1) attachment while standing in the spacecraft restrained by the command pilot, (2) attachment while standing in the spacecraft unrestrained, and (3) attachment while outside the hatch.

Following the camera placement evaluation, the astronaut was to proceed down the handrail to the nose of the spacecraft, evaluating tethered dynamics along the way. The astronaut was then to connect the Agena tether. This tether was a 100 foot long, 2 inch nylon web tether connected on one end to the Agena vehicle. The free end of the tether terminated in a multi-strand cable loop, which was to be manually attached to the docking bar by the astronaut during the EVA. The loop was locked onto the docking bar by the handhold clamp shown in Figure 5-5 . The astronaut was to perform this task while connected to the hand bar and docking lip by waist tethers. The Agena tether task was substantially the same as the one which proved so difficult on Gemini XI. The astronaut was to activate the S-010 micrometeorite experiment from this position. This task was similar to that described in the previous discussion of GT-X.

The astronaut was then to move to the adapter and perform the adapter work station tasks. The purpose of the work tasks was to evaluate the effectiveness of the two restraint modes in performing various subtasks. The subtasks included: (1) evaluation of two types of velcro (nylon, stainless steel), (2) operation of various electrical and fluid quick disconnects, (3) evaluation of cutting type tasks and (4) performance and evaluation of torquing operations. While in the adapter the astronaut was also to evaluate suit mobility characteristics. The astronaut was then to proceed to the Agena work station to perform a series of similar tasks evaluating tethered versus untethered restraint mode. The subtasks included: (1) fluid connector operation, (2) evaluation of portable velcro handholds and pip pin restraint anchors, and (3) evaluation of the Apollo torque wrench and torquing capability.

Interspersed throughout the time line were a number of camera activation and film changes as well as eleven, two-minute duration rest periods. Following the Agena work tasks the astronaut was to return to the hatch and ingress, ending the umbilical EVA. The performance in space and the simulations closely followed this format with only minor changes. The following sections detail the performance in space as well as in the simulations.

5.2 - TIME LINE COMPARISON - *A detailed analysis of the orbital and simulation time lines was performed to determine areas of similarity and dissimilarity in task time and astronaut motion. Tables X, XI, and XII present the results of the final iteration of the time lines for the water immersion simulation, the flight and the aircraft simulation, and details the task performance times and the task description. Specific comments are made to indicate anomalies or pertinent observations. Sequences of selected tasks are given in Figure 5-1, comparing the flight, water simulation, and aircraft simulation on a five second increment basis. Figure 5-2, a continuous sequence of the XII time line for the water simulation and Figure 5-6, a continuous sequence of the flight, are presented for reference purposes. The sequences comprise pictures on a 30 second increment basis. Figure 5-7 is a similar sequence of the available film from the zero gravity aircraft simulation.*

Handrail Deployment - *Handrail deployment was not an element of the umbilical EVA. This task was performed during the first standup EVA period. Since underwater simulation presented an excellent mode to evaluate this task, and because the success of handrail erection was considered critical to the overall umbilical EVA, a handrail erection sequence was performed at the beginning of each preflight water simulation film. A comparative film sequence is shown in Figure 5-1. The flight sequence is shown in the upper line. Directly below this is the sequence from the water immersion and zero gravity aircraft simulation runs.*

Astronaut Aldrin began handrail deployment at an elapsed time (GET) of 20:27:14, immediately following the adapter handrail deployment. The erection task lasted 115 seconds. The same task performed in the water simulation lasted 145 seconds. The motions in both modes were very similar. The time difference is attributed to difficulties in deploying the telescoping sections of the handrail in the water simulation.

Since the handrail task duration exceeded the time duration of one parabola in the zero gravity aircraft (approximately 30 seconds), it is difficult to compare aircraft simulation data. An interruption in the task is noted on the original film. The total task time for handrail erection in the zero gravity aircraft appears to be 40 seconds. This follows the normal pattern zero gravity task performance in aircraft versus water simulation. It was found that in most cases the task time tends to be markedly decreased in aircraft simulation over actual performance or water simulation. This may be due to the psychological factor that a zero gravity parabola gives only limited time to accomplish a task. The more familiar a subject is with this simulation mode, the less this factor tends to be a problem with proper task planning. Pilot Aldrin commented that the handrail erection was "quite easy" in both simulation modes and was equally easy in flight. In a postflight debriefing, Aldrin described his movements in performing this erection task in orbit.

Standup Familiarization - *The first major umbilical EVA task was standup familiarization. The object of this task was to give the pilot* *time to adjust to his new environment. The only work tasks scheduled during this familiarization were subjective evaluations, which required small physical exertion. The majority of the time during this task could therefore be used by the astronaut in "getting the feel" of the umbilical EVA mode.*

The previous standup EVA had provided Pilot Aldrin with an excellent introduction to the EVA environment. Aldrin commented on the usefulness of this first standup EVA in a postflight debriefing.

> *Aldrin* - *"I was quite thankful that we did have the standup EVA first because it gave me an opportunity to see just how small the forces were that were required to get the body moving. I'm sure also that having this standup EVA first, with its smaller priority than the umbilical EVA, tended to have slightly lower psychological effect if there really was any in terms of effecting any mental tension or something that might have impaired the activity or changed heart rates...'*
>
> *"I'm glad that we did that one first instead of the other one. It put me in much better shape because then I could devote all my attention to the particulars of the umbilical EVA when that came up..."*

A short umbilical attached directly to the suit intake system was utilized during the standup EVA. This effectively tethered the pilot to the spacecraft cockpit and limited his movements. The long umbilical changed the pilot's configuration considerably. His overall volume increased with the addition of the chestpack (ELSS), and his freedom of movement was extended to the length of umbilical. Because of these variations, it was felt that another familiarization period was necessary to allow the pilot to orient himself to this new configuration. Standup familiarization apparently accomplished this objective. All indications show that Astronaut Aldrin was both physically and psychologically prepared as he moved into the subsequent task line.

Aldrin's orbital standup familiarization included an evaluation of free floating dynamics and ELSS outflow characteristics. The total task interval was 100 seconds. In his preflight water simulation, Aldrin spent only 50 seconds on this same task. The majority of this task time was utilized for the free floating dynamics evaluation, since the ELSS mockup in the water was of low fidelity.

Aldrin first attempted to release his hand grip and evaluate any resulting forces. Regaining his hand hold position, the pilot attempted to change his positions with minor hand movements noting any particular forces involved. Aldrin's orbital dynamics evaluation was similar to his preflight evaluation, except that he did not have a command pilot in the water simulation to steady his position with the leg tether, Figure 5-8 . While the pilot evaluated free floating dynamics in orbit, the command pilot released his hold on the leg tether.

The ELSS outflow evaluation was a simulated maneuver in the water and, in effect, Aldrin passed over this subtask completely in the simulation. This explains the difference in time between the orbital and simulation evaluations. No aircraft data on standup familiarization was available. In the postflight debriefing, Aldrin indicated that the dynamics evaluations are not particularly suited for aircraft zero gravity simulation due to aircraft perturbations.

> *Aldrin - "In the zero g airplane, it is extremely difficult to attain this pure zero g and we never really know whether we're working against a small perturbation in the aircraft trajectory or whether this is an actual response that we have."*

Immediately following the standup familiarization period, the command pilot requested that Aldrin rest. This procedure was a variation from the simulation time line. During the preflight simulation, the pilot began the retro-adapter camera placement immediately after his standup familiarization. The first two minute rest period was scheduled in the water simulation following the evaluation of the methods of camera placement.

Aldrin's first orbital EVA rest period lasted 52 seconds. He commented that this rest did not seem necessary since no real activity had occurred during his familiarization period. At this point the rest period was cut short and the pilot began the camera placement evaluation. In the postflight debriefing, Command Pilot Lovell commented on this rest period and the overall rest schedule.

> *Lovell - "Our time line for the umbilical EVA was based on the ones we have done in the water. We allowed eight minutes for the unlatching of the spacecraft hatch to the final jettisoning of the waste pouch, and the pilot getting up and outside the hatch by standing up. We were actually very conservative on the time and completed this prior to the eight minutes we allowed. It (the first rest period) was just too soon. The way we managed to hit the proper hatch opening time, and be ready at the same time, didn't allow us to sit around. We weren't rushed during the umbilical EVA preparation. Of course, the EVA was designed to get the most out of basic EVA with rest periods to anticipate any problems which we might encounter. We took the rest periods as they came along, however, it was getting obvious to me that rest periods which we had allotted were either too long or too frequent. We managed to stay on the time line throughout the entire umbilical EVA."*

The first orbital rest period, elapsed time 1:52 (0:00 elapsed time is set at the start of standup familiarization for comparative purposes), came before the elapsed time of the first scheduled rest period of the preflight simulation (4:35). During the preflight simulation, the first rest period was interrupted by an optical surface evaluation. Aldrin *attempted to clean the command pilot's hatch window using a wiper cloth located in a pouch on his lower leg. The optical surface evaluation lasted 55 seconds, separating the two segments of the first 60 second rest period. A similar optical surface evaluation, also lasting 55 seconds, was performed at an elapsed time of 112:15 in the orbital EVA. A possible reason for this change in schedule was the concern over adherence to the planned time line. The optical surface task was considered of secondary importance and was placed near the end of the umbilical EVA time line so that it could be omitted, if the mission fell behind the time line schedule.*

Camera Placement Evaluation - Immediately following standup familiarization in the simulation time line and following the first orbital rest period, Pilot Aldrin evaluated various placement techniques for the EVA 16 mm motion picture camera. During this camera placement evaluation task, Aldrin attempted to determine the best body configuration for camera installation and positioning. Figures 5-9 and 5-10 show two body positions evaluated during the preflight simulation. Aldrin describes the task in his postflight debriefing and comments on its purpose.

> *Aldrin - "We had three different ways of mounting the camera. The first two were essentially the same as the standup EVA. I was really still inside the cockpit. The next one, I was completely out and switched over to having the right hand on the handrail and the left hand taking the camera off and then putting it back in. This was quite a different method of putting it in than the other two. It required the use of one hand and a little bit of torquing operation with that hand to get the camera into position and put it on down. But, again, this didn't appear to be any real difficulty. The thing we are trying to find out is, in going back and forth putting the camera up and taking it down, did you want to go through the procedure of getting back in the hatch, as far as your feet go, and using the left hand on the seat to put the camera in, or could you do this in passing? Could you stop there and put it up? If you could, then you might be able to save a little bit of time."*

Comparison of the simulation and orbital data indicates that it did not matter whether the pilot was inside or outside of the spacecraft cockpit, or whether his legs were restrained or unrestrained. As long as a handhold could be maintained to counteract reactions created during camera attachment, the task was not difficult.

Following camera placement evaluation, Pilot Aldrin began his second orbital rest period. At an elapsed time of 6:54, Aldrin is lagging the preflight water simulation time line by 139 seconds. The first rest and the longer standup familiarization and camera placement tasks account for this time lag. This second orbital rest period corresponds to the first rest period in the water simulation.

Aldrin positioned his body outside the spacecraft cockpit, and began this rest holding on with both hands to the portable handrail. This was the same position used in the preflight water simulation. Figure 5-11 shows the position Aldrin assumed in the water simulation. The pilot stated during this rest period in orbit that he had to get proper position and "hold onto something" to rest. The same situation was noted during the preflight simulation. The first rest in the water simulation lasted 65 seconds and was interrupted by the optical surface evaluation. The second rest period in flight lasted 103 seconds. The optical surface evaluation was postponed until much later in the flight. The original flight plan called for rest periods of two minute duration. Most rests in both orbital and preflight simulation modes did not attain this scheduled length.

Before moving forward to the spacecraft nose, Pilot Aldrin extended the umbilical out of the cockpit. In orbit, Aldrin was assisted in this maneuver by his command pilot. The task was initiated at an elapsed time of 8:37, and required 65 seconds to complete. During the preflight water simulation, Pilot Aldrin had to simulate the extension since the umbilical was already out of the cockpit. This was necessary because of the construction of the mockup umbilical and since the command pilot was not in the spacecraft mockup. The low fidelity of these important hardware elements caused the actual orbital task line to slip farther behind its mission time schedule.

Movement to the TDA - Movement along the spacecraft began at 9:47 (ET) in the flight. Aldrin's objective was to move from the hatch area up the portable handrail and position himself on the handrail at the spacecraft nose and Agena target docking adapter (TDA) interface. The movement required 41 seconds. Figure 5-1 shows the comparison sequences of this movement for the flight and preflight water and aircraft simulations. The movement task in the preflight water simulation lasted 31 seconds and 8.1 seconds in the aircraft simulation. This movement is equivalent to an average velocity of 0.16 ft/sec for the flight, 0.22 ft/sec for the water simulation, and 0.64 ft/sec for the aircraft simulation.

This particular movement task is very useful from the standpoint of motion analysis. All three modes yielded excellent film coverage as can be seen from the pictorial sequences. Aldrin made a 180° turnaround during this forward translation. In his orbital EVA, Aldrin made this turnaround in the opposite direction from that of the preflight training session. When viewing these films together, the two modes are kinematically identical. The small time differences between the water simulation and the flight performance are probably due to the astronaut's analytical evaluation of movement in space. The large difference between the aircarft translation time interval and both orbital and water modes substantiates the premise that many tasks are "hurried" due to the zero gravity parabola time limitations.

Rest Evaluation on Waist Tethers - The astronaut completed this forward movement by attaching his waist tethers in preparation for a rest period. The right waist tether was attached first to an attachment ring near the forward end of the handrail, Figure 5-12 . The left waist tether was attached to one of the u-bolts on the docking cone, Figure 5-13 . In orbit, Aldrin began this tether placement at 10:35 (ET) and both tethers were attached 25 seconds later. The same maneuver in the preflight water simulation began at 7:01 (ET) and lasted 37 seconds. In the aircraft simulation, Aldrin attached both tethers to the u-bolts on the docking cone, beginning with the left waist tether. The tether attachment in the aircraft mode took 26.4 seconds.

In both the preflight and flight, the rest period began immediately after the waist tethers were attached. The object of this rest was to evaluate the effect of resting on tethers only. After attaching the tethers, the pilot released his hold on the handrail and ceased activity. Aldrin's observations on this evaluation are presented below.

> Aldrin - "The tethers didn't seem to jerk me back in at all. They just eventually assumed a natural position and I was drifting very lightly, maybe in one direction, and then perhaps my foot would contact it and I would bound back a very slight amount. A very comfortable rest position."

The orbital rest period lasted 78 seconds, whereas the same rest period in the preflight water simulation was only 53 seconds. Aldrin again noted that he did not need a rest period at this point, since he felt no physical need to rest. Once he was satisfied with his tethered evaluation he terminated the remainder of his rest period.

Agena Tether - After completing the rest evaluation in the water simulation mode, Astronaut Aldrin repositioned his waist tethers in preparation for the Agena tether task. This positioning operation required 20 seconds of extra movement and thus extra energy expenditure. Aldrin used this simulation experience to his advantage in orbit. Pilot Aldrin intentionally spread the tethers apart to "give a little broader stance to go ahead and hook up the Agena tether" in the flight. This eliminated the need for tether repositioning and streamlined the time line placing Aldrin in an ideal position for immediate activation of the Agena tether.

The Agena tether task consisted of two separate subtasks. First, the pilot installed a wire loop over the spacecraft docking bar. This wire was attached to a nylon tether to be used in a later experiment on gravity gradient stabilization. A slip-loop configuration allowed the pilot to tighten this wire on the bar and position it at any desired height. Figure 5-14 shows the Agena tether configuration before it is deployed on the docking bar. The deployed position is shown in Figure 5-15. In the second part of the Agena tether task, the astronaut removed the docking bar clamp from its position on the TDA and installed the combination clamp/handgrip on the docking bar. The function of this clamp was to hold the tether wire loop down on the bar preventing possible snagging of the Agena tether when the spacecraft and Agena parted later in the mission. Although the docking bar was also to serve as a handhold position, Pilot Aldrin later decided that the clamp was not operating properly, and discarded this use so as not to jeopardize the subsequent tether experiment. The comparison sequences for the tether activation task are shown in Figure 5-1.

Activation of the Agena tether began at an elapsed time of 12:23 in flight and lasted 140 seconds. In the water simulation, activation of the Agena tether began at 8:57 (ET) and took 100 seconds. The Agena tether activation required 40 seconds more in flight than the same task in the water simulation. This may be explained by three characteristics. First, after installing the docking bar clamp, the pilot removed a small two foot length retainer tether from this unit. This tether was not removed in the preflight water simulation. Second, Aldrin found the "toadstool" atop the docking bar loose when attaching the docking bar clamp in flight. He paused for a short time to evaluate this problem. No real delay was caused here, and the loose "toadstool" posed no serious problem. Thirdly, when Aldrin began the Agena tether task, both he and Command Pilot Lovell noticed that fast movement affected the Agena spacecraft stability. To eliminate this problem, the pilot deliberately slowed down his movements. This third factor probably accounts for the entire variation. The activation task required 35 seconds in the aircraft simulation. Because of the length of this task and the broken film sequences received from this simulation, it is difficult to determine an exact time interval. However, it can be seen in the film that this task appeared to be rushed during the aircraft simulation mode.

S-010 - At the completion of the Agena tether task in flight, another change occurred. Before moving to the S-010 experiment, Astronaut Aldrin began a rest period at 15:52 (ET). The third orbital rest period was the first to reach the full scheduled time duration of two minutes. The rest period lasted 127 seconds and was preceded by a 38 second rest preparation. During the preparation, Aldrin altered his tether placement so that he would be in the best position to immediately activate the S-010 after his rest. In the preflight water simulation, Aldrin did not take this rest period. Following the Agena tether activation, the pilot moved immediately into position to activate the S-010 experiment at 12:32 (ET).

S-010 activation was simulated in the water time line because of low fidelity mockup characteristics. Aldrin spent 55 seconds reaching the positions that he considered necessary for S-010 activation. The interval, however, was not realistic. The actual orbital S-010 activation lasted 219 seconds. Aldrin experienced minor positioning difficulties, but no major problems occurred in his orbital activation.

In Figure 5-16 , the S-010 is seen fully deployed on the TDA. A comparison sequence of S-010 activation in flight and in the water simulation is presented in Figure 5-1 .

The addition of a rest period after the Agena tether task in the orbital EVA and the fact that the S-010 was simulated in the preflight water EVA caused further deviation from the planned time line. Upon completion of the S-010 activation in flight, Aldrin repositioned his tethers in preparation for the TDA work station setup task. The same tether repositioning task was performed in the preflight water simulation at 13:27 (ET). This repositioning task took 40 seconds in orbit. During this time, he moved from the S-010 position on the Agena to the TDA work station area. At the end of the repositioning task in the simulation, Aldrin removed the velcro protection covers from the work station area. This increased the time required for preparation to 75 seconds.

TDA Work Station Preparation - Aldrin immediately began the initial portable handhold and pip pin placement in flight. The initial setup preparation took 66 seconds. Aldrin comments on the purpose of this task in his debriefing.

> Aldrin - "Having done this I then moved around to make another change in the tether location, the purpose here being to deploy the portable handholds and to preposition them and locate pip pins on the work station so that we'd have that much more time left after the adapter work to make the complete evaluation of the work station."

The command pilot interrupted this initial setup preparation, suggesting that Aldrin begin his fourth orbital rest period, commenting that they were ahead of their time line. Aldrin elected to utilize this rest period to send messages to Houston. Following these messages Aldrin completed his rest period and his work station setup preparation. Aldrin's description of these tasks follows.

> Aldrin - "We had time left during the stateside pass and I wanted to deploy the two flags that I had stowed in the portable handhold. It looked like in order to do this, in the way with least jeopardy, would be to do it before I pulled the pip pins out, instead of trying to take two hands to do it. So I pulled them out and said a few words about Veterans Day and said a few more words about the Army-Navy game. I took the Veteran's Day flag and tossed it in the breeze. I took the other flag and tucked it as tightly as I could in the right side of the ELSS, between where the hoses were between the ELSS and my chest. I then went about the task of deploying portable handholds. I took each pip pin out and in turn put it into a holder that I wasn't going to use with the portable handholds that were going to come up from the adapter. I chose free pip pin attachments. They were the ones that did not have stars. I wanted to then evaluate afterwards and compare a freely swinging pip pin as a handhold with the ones that were rigidly mounted in the stars. I put the two portable handholds in the outboard position, both on the left and on the right leaving room for the others to go in the inboard. I took the one remaining pip pin at this time and put it

on the left side of the Agena as you face the Agena from the spacecraft, to get it out of the way for both the torquing operations and also so it wouldn't be in the center when the chest pack lights hit it. About this time I received a call from Houston to slow down a little bit. It was perhaps just after the little blurt about Veteran's Day and before deploying a portable handhold, as previously discussed in the medical briefing. I think that some of the reasons for the change in heart rate was the audience that I was addressing and I wanted to make sure that I didn't flub. There wasn't much of a rest period while I was deploying the portable handholds. I did pause there for a minute and before I started back, I did get the word from Houston that the recovery was good which meant the return of the heart rate back down to normal."

The task time intervals for the work station preparation and the rest are given in Table XI . The subsequent movement followed by a camera change, GLV strip retrieval, and a camera retrieval task shows no significant time variations between the orbital and water simulation modes. In all cases orbital task times were slightly longer than the simulation, Table XIII.

<u>Aldrin</u> - "I then started moving back along the handrail. I had to take the waist tethers off now, one at a time. I took the right one off and put it back on the ELSS. This time I took the left one and instead of attaching it to the folding bar with two rings on it, I stuck it with velcro on top of the chest pack. This bar that went across, I think was less than optimum in design. I had some experiences in training with it coming off and I thought that I might just as well leave it loose and not bother using it and try using the velcro instead..."

Prior to the movement from the spacecraft hatch, Aldrin extended additional umbilical out of the spacecraft for the maneuver back to the adapter. In the simulation mode the umbilical was not stored in the spacecraft and extension was unnecessary. The movement to the adapter took 12 seconds from the spacecraft hatch to adapter pigtail in flight. In the simulation this movement took 145 seconds. This time variation was caused by two interruptions in the simulation to position the "snaking" umbilical. A description of this motion in flight was given by Aldrin.

<u>Aldrin</u> - "about that time, we fed out the remaining part of the umbilical. I stopped about this time to make sure that the umbilical looked like it was routed in the proper fashion and wasn't tangled around anything. It seems to me as I started moving along the handrail that the umbilical did start to snake ... I started moving back from that position along the handrail going back right hand first so that the left side of me where the umbilical was attached, was trailing so that the umbilical was out behind me and moved back out toward the adapter toward the pigtail. As I got to the edge of the equipment adapter, I could see that

the loose primer cord that I had noted during the first standup EVA was not as really loose in that there were not so many pieces around there to present any problem at all. I just forgot about trying to pull any of that off. With my right hand I got a hold of the pigtail and made sure that it was secure and locked and wouldn't swing freely. From that position I pushed a little bit to the rear of the spacecraft and made sort of a combination turning maneuver by pushing to the rear and then restraining myself from going further to the rear by holding on the pigtail. The net effect was to turn me around the corner. I turned around the corner and with right hand first, I got hold of the handrail back in the adapter. I found myself in pretty good body position to get ready to thread the umbilical through the pigtail. Around in this area it seems to me that I did have to use a little bit of torque with one hand on the pigtail to push my feet down a little further because my head was tending to float up at the time that I was going around the corner."

At this point in the time line the pilot experienced an interesting information crossover from the simulation. The original Gemini XII EVA mission plan was to evaluate the astronaut maneuvering unit (AMU). Aldrin was training for this mission when the AMU configuration was cancelled. The mission update included changes in the foot restraint position. When preparing to enter the adapter work station, Aldrin experienced a moment of disorientation.

Aldrin - "I then started moving toward positioning myself in foot restraints. I guess that one becomes so used to going from this position to the foot restraint directly as in the AMU operation that I looked down for the foot restraint and all I saw was a blank recess in the thermal curtain where the AMU foot restraints were going to be. I thought, gee, what happened to the foot restraints. I can't even see them. They were up the other way so I had to yaw around to the right which meant that my feet now were going about where the umbilical was coming through the pigtail."

This emphasizes an important asset of the underwater training simulation which the astronaut commented on in the debriefing.

Aldrin - "There are two ways that you can go through the umbilical. You either find yourself going through it headfirst and the umbilical would then be around you, or you find that the umbilical is in front of your feet and you've got to step over it. Both of these situations I had experienced under water and had been able to step through it by holding on the umbilical and with its own stiffness direct it with your hand away from your feet. It tends to move away as you can bend your legs a little and move them through. If it is the case of moving it over your head, why that's fairly easy to do also. Then I moved so that I had one hand on both of the handrails and sort of lowering my body down into the foot restraints."

<u>Adapter Work Station Camera Placement</u> - *The flight time line continued to lag behind the simulation time line. The pilot spent considerable time trying to fix a broken linkage in the camera bracket, and in trying to determine if the camera was operating in flight. This required approximately 142 seconds. Camera placement in the simulation took 73 seconds. This task was followed in the simulation by a period of neutral buoyancy adjustment.*

<u>Rest</u> - *Aldrin rested for 111 seconds after his rebalance break. This was his fourth rest period in the underwater simulation. The rest period in flight lasted 57 seconds. Aldrin interrupted this fifth orbital rest period to begin the foot restraint evaluation. The task sequence varied from the simulation at this point. In flight, the astronaut placed the umbilical in the umbilical clip before his rest period commenting that it was more convenient at the time. In the simulation, the pilot spent 103 seconds prior to the foot restraint evaluation placing the umbilical. Here again the simulation experience streamlined the astronaut flight performance.*

<u>Foot Restraint Evaluation</u> - *The foot restraint evaluation took 2:50 in flight. This was 83 seconds longer than the same evaluation in the water simulation. Astronaut Aldrin described the orbital foot restraint evaluation and its purpose in his debriefing.*

> *<u>Aldrin</u>* - *"At this point we went through an evaluation of the foot restraints as far as total mobility goes. What I really intended doing was to compare in a subjective way the amount of mobility that a person has with these foot restraints in comparison with things that I had experienced both from the zero g airplane and under water. I did this by moving from the left over the right and standing myself up a little bit and back down bending my body down to get to the top and the bottom of the work station. I wanted to see just how well leaning back compared to underwater operation and in the airplane. Up to this point, everything was very, very similar in the way that the foot restraints allowed me to move my body around. Even in leaning back, it seemed as though I could do this quite well. I did note that there was a little bit more leg tension required to lean back to the same degree. That is, leaning back so that the axis of my back was essentially parallel to the spacecraft longitudinal axis. To hold this position required a fair amount of force on the legs. When I released this I gradually drifted back up. It is very easy to hold a neutral position from 30 to 40° rolled from the foot restraints to roll right. You could also pitch back about 40 to 45 degrees with very little strain or force and you could turn your body somewhat to each side. The real test of course comes when you start to do torquing type operations where you exert forces against the top of the boots. This is the prime purpose of them to keep you from floating away from them. I think both Gene and I decided in our training that the foot restraints, if they operated as they had in training, that they would enable a person*

to do just about any task that he is able to do in 1 g. If we establish that this was in fact true, then we would move on and do things on the waist tether. I can say now that the best restraint system that we have ever seen for doing any EVA work is undoubtedly foot restraints. We don't want anyone to think that just because we've concentrated on waist tethers that they are better. They are not. Foot restraints give you the best freedom of action. They give you the best restraint system for operating and a fairly wide region with respect to the foot restraints. You can't move too far afield, just by the fact that they are fixed. I think if I had to compare foot restraints located in a certain place for an optimum work station with a waist tether hookup that was also located in an optimum fashion for that same work station I think that you have more freedom of action with the foot restraints."

Work Station Preparation - *Following the foot restraint evaluation, Aldrin deployed the work station penlights and tried to activate the camera. These tasks took 38 and 40 seconds respectively in flight. The pilot began his sixth orbital rest period at this point. The rest lasted 2:09, and was followed by another attempt to activate the work station camera. This second activation attempt was also unsuccessful.*

In the simulation the foot restraint evaluation was followed immediately by the fifth rest period. The task sequences differed in the flight and simulation modes because Aldrin's simulation training allowed him to optimize his flight time line. The failure of the camera was an unexpected problem and caused further slippage in the time line.

Adapter Work Tasks - *Tables XIV and XV are detailed analyses of the adapter work tasks for the flight and the simulation. The first work task performed was torque evaluation. Difficulty in removing the torque wrench from its pouch caused the task to extend far past its scheduled time. The torquing operation was to be performed first on a 1/4" and then a 1/2" fixed bolt shown on the bottom center of the adapter work station, Figure 5-17. The torque wrench was equipped with a visual readout gauge and could operate in both clockwise and counterclockwise directions. The astronaut evaluated torque operations first in clockwise and then in a counterclockwise mode at the 12, 3, 6, and 9 o'clock positions, commenting as he proceeded. The torque evaluation was first performed using the foot restraints only. In a subsequent period, he attached both waist tethers and re-evaluated the task. He noted no particular difficulty in exerting torque at any of the positions evaluated in either flight or preflight modes. Aldrin describes this orbital task in his debriefing.*

Aldrin - *"Going to some of the tasks in the adapter, the pouch opened up rather easily; the wrench had a strap around the handle and it looked like this wasn't velcroed in; that it was stitched in. Evidently there was a loop in this nylon strap that* *was made just the right size for the handle to slide into. Well the heat must have gotten into this and shrunk it up because when I went to pull it out, it wasn't about to come underneath this strap. I looked to see if it was velcroed and it didn't appear to be at all. This cost maybe a minute or so to try and figure out just how to get that out. I pulled just straight away on the wrench; it didn't line up the way the strap was on it. It tended to be twisted which didn't let it slide freely. So, I had to get two hands in there and pull in the area where the strap was and pull the wrench out, and it finally came loose. The wrench looked like it was in good shape, so I proceeded to the torquing operation, which consisted of looking at clockwise operation at four different places around the clock and then reverting to a counterclockwise operation. This was on the 1/4 inch head bolt. I found that the second time I torqued the wrench up to what I felt was a near maximum level without really straining myself; this was in the vicinity of 200 to 250 inch pounds, the wrench snapped in some fashion. But when I looked at the pointer, it was no longer zeroed. It was sitting at about the half-way point. I didn't think it was particularly meaningful to evaluate any torque numbers that I was able to read out from that point on. I tried to just torque it around to reach about 180 degrees from where I started out. I figured that that was a near maximum torque."*

The second task was an evaluation of an electrical connector. Three electrical connectors were available in the adapter work station; a starboard, a port, and a center connector. The starboard and port connectors were attached by a multi-strand cable. A center connector separated the cable into two halves and required a two handed operation. The connection broke into units of approximately equal lengths and diameter. The two sections were mated by lining up colored index marks and press fitting them into one unit. A lever on the left section was then manipulated to tighten and lock the unit. The disconnect procedure was the reverse of the connection operation.

Aldrin commented that the center connector was slightly more difficult to line up than the others. This was accentuated on waist tethers when restrained by the foot restraints. Aldrin suggested the use of only one index mark painted with a light color to expedite the connection. It became difficult to distinguish and match the multi-colored index marks on the connector in low light conditions in space. Using a light color such as white, and only one mark identification would be simplified.

Aldrin - "The center connector; there was no particular problem in doing that. I had to unpack the velcro first before I could get it free. It's a two handed operation. With two hands and a good restraint system there is no problem at all in lining something up, because you hold it right in front of you, both ends were loose. That kind of an operation is very easy. Part of *that made it difficult was that once you had them lined up, and while they were still lined up and you were pushing them together, you had to find a finger somewhere or thumb that you could start turning this locking device that only had one pin that stood out on it. There may be another way to do it. Maybe you could just grab a hold of that part right there and push it into the other one and turn it. Maybe I've been doing the whole thing a little bit more difficult than it should have been. But if that's the case, then the index marks are useless, because in grabbing ahold of the thing, you would cover up completely the index marks. We ought to be able to afford to put more prongs out there than just that one for that kind of a task. You just don't hook something up and then take your hand off and find out where this thing is."*

Lovell - "Do you think the four prong, that we had on there originally was better than the one prong?"

Aldrin - "There is no doubt about it; four are better, you don't have to pre-position the locking device. You can just leave it wherever it is and you can always get ahold of one prong or the other. If one of them doesn't engage the first time you turn it around, you can catch the next one as it comes around. The situation that comes up with the one prong is that you position it where you think it is going to be okay, you put the two together, and you find that you've got to push it all the way around. So, now you've got to bring it back again and recenter the things."

At the end of the center connector evaluation, Aldrin took a scheduled rest. The time interval for the rest period in the simulation was two minutes, in flight the rest interval was 1:35. Aldrin noted during this seventh orbital rest period that a crease in his right glove was beginning to "give my hand a little bit of a problem." He made no mention of this problem later in the flight or in his debriefing.

The second session of adapter work tasks began with an evaluation of the cutter tool. In his debriefing the astronaut discussed this task and its comparison with previous training simulations.

Aldrin - "The cutters were painted black. It looked like a heavy coat of black paint. The restraining system on the cutters worked fairly well. It takes a little extra time to open it up, put the fingers with your hand into it, and then tighten the strap on top of it, but I think that work is well worth the effort because during any subsequent operation with it you just don't worry about where that cutter is because it is sitting right there on your hand. The unlocking of the cutters was not too difficult. I think that strap that was on them was a little bit too long. Cutting the wires......I cut the medium one first and took a little bit more effort with one hand than I thought it was going to, but on the *second squeeze it cut through without too much difficulty. Then I took the smaller strand and cut through that quite easily the first time. Then, I went to the fluid QD. I'd never been able to cut one of these before in training periods because the cutters were either rusted from underwater operations or we were maybe saving this for some other work. I had tried it with training cutters, both one hand and two hand, and was unable to get through the wire. I tried that a couple of times and saw it just wasn't going to make it. So, then I moved over a little bit in the foot restraints and got both hands on it and squeezed hard and it cut it in two.*

I think that this points out that this kind of a task would have been impossible without a very good restraint system. I think the waist tethers would have handled that if you could have stayed in position, if the work station was up high enough. The two foot restraints enabled me to get over there in good working condition to get both hands to squeeze on it."

The command pilot realized that their flight time line was falling behind the water simulation flight plan, and from this point on he attempted to keep the pilot on schedule. The water simulation cutter task lasted 3:25. Aldrin used 3:29 for this same task in flight.

The astronaut stowed the cutters and began an evaluation of the adapter work station pip pins and portable handholds. In the water simulation, Aldrin spent only 48 seconds on this evaluation. He noted that the portable handhold velcro did not seem to be "holding up" in the water mode, and he felt that this was the reason the torque load capability of these handholds was low. His subsequent orbital evaluation showed, however, that the water simulation had been quite accurate in depicting the torque capability of the portable handholds. Aldrin took 2:04 to evaluate this task in flight.

Aldrin - "The pip pins came out without any problems and stowed in the star fittings, and I positioned them so that they wouldn't get in the way of any torquing operation or the left hand disconnect. Handholds were repositioned so that they were in a slightly better location as far as not interferring with the waist tether hookup. The velcro on the portable handholds gave a very shaky handhold really. I didn't get a chance to fully evaluate the handholds as far as how much torque you could put on them back there, but it wasn't very impressive at all. I think you'd be better off grabbing hold of just about anything you know is secure. It may not be as good a handhold as the portable ones are. Of course, if you have nothing on a flat surface the you have to put something on, but that velcro just didn't appear to be adequate at all to go into that kind of an operation."

In orbit, Aldrin began the Saturn bolt task with a 1:49 evaluation in the foot restraints. The task consisted of removing and replacing a *bolt mounted in the lower center of the adapter work station. Aldrin attached his waist tethers and removed his feet from the foot restraints after determining that bolt removal was extremely easy when using the foot restraints. Aldrin spent 1:50 removing the bolt from its receptacle using waist tether restraints. The rubber retainer strap designed to capture the bolt when it was removed did not function as was expected. Aldrin describes this task and the problems involved in his debriefing.*

> *Aldrin - "I took the wrench off the velcro and started working on the Saturn bolts; torqued it out to about a half way position where it was obvious that it was fairly easy to work from that point on. As in training, I found that in trying to rachet it back to the free wheeling position it also tended to turn the bolt back in again. So, I had to put a side force on the bolt and wrench during this operation and enough friction in the bolt and its threads so that it would overcome the rachet friction so that I wouldn't lose everything I had gained in the previous stroke. When I got to this point, I decided, well, I'll take it out the rest of the way with my fingers. I said, well, it looks like this operation will be fairly simple so I'll stop at this point and stow the wrench and do the rest of it in the waist tether. I hooked up the waist tether to the lower attach points and took my feet out of the foot restraints, tightened up the waist tether to 3 to 4 inches from full extension. The waist tether attach points relative to the Saturn bolt operation is far from optimum. The waist tethers are far too close. The right waist tether gets in the way of the wrench as it's turned and the left one is just too far up to get a good spread type of stability for any differential body torques that you need. But we knew that right from the beginning. So, I used the wrench and loosened it up just a little bit more and put the wrench away and started taking the bolt out with my fingers, twisting it out, and I discovered that the retaining washer that had been put on there attached to the rubber, wasn't coming out with the bolt. It was staying attached to the protrusion in which the bolt was screwed into. So, I got the bolt all the way out and was holding it in my right hand and then with my left hand I tried to loosen the rubber because this whole arrangement was covering up the other hole that I was supposed to put the bolt back into. So by pulling away at the rubber it finally came loose. The reason that it was stuck I'm sure again was the heat problem melting a little bit of the rubber against the metal."*

The difficulty encountered with the retainer ring caused Aldrin to use both hands in removing the bolt. The use of two hands, close to the body, is sometimes a difficult task in the G-4C space suit. The astronaut noted that this particular operation was tiring, and, at this point, he interrupted the Saturn bolt evaluation and took a 1:04 rest period. Following this eighth orbital rest period, Aldrin continued his Saturn bolt evaluation for 3:01. During this period, he replaced the bolt in its receptacle, commenting that the "Saturn bolt workspace is way too close to the waist tethers."

<u>Aldrin</u> - "Then I started trying to position the bolt to get it in and it didn't want to aline properly. I was using the left handhold, I think, trying to line it up. I started twisting, trying to very gently line it up so that it was lined up perpendicular to the hole. I twisted it, trying to engage it, however, this took, perhaps, four or five attempts before I finally got the threads to engage. I tightened it up with my fingers to about the half way point and picked up the wrench and changed the setting on the wrench and started torquing it up again. And again I found that I was unracheting about everything I was putting in trying to tighten it up so I had to use that technique of either holding the socket with my left hand, so that it didn't undo what I was tightening up, or to put a twist on the bolt creating a torque against the threads, while I was in the recovery position from the tightening operation. It finally tightened all the way up and got it to a reasonable high torque level and then we forgot about that operation."

In the water simulation time line, Aldrin did not take a rest period during the Saturn bolt evaluation. After a 1:43 evaluation of the bolt using the foot restraints, Aldrin attached his waist tethers and spent 6:47 removing and replacing the bolt. It is interesting that the same difficulty was encountered in the simulation with the rubber retainer strap. The pilot commented that he "broke the retainer strap" during the loosening operation.

The next scheduled task was an evaluation of the proper size hook and rings to be used for semi-permanent equipment retention. The hook and ring evaluation took 3:23 in space and lasted 3:20 in the water simulation. In his debriefing the pilot describes the details of this orbital evaluation. Except for small variation in the hardware the simulation task was essentially the same.

<u>Aldrin</u> - "We went into the hook and ring connection and this operation was quite similar to the underwater operation. I think under water the hook and the ring both, of course, don't float as they do in space. I took the big hook and hooked it to the big ring and the little hook to the little ring and then a modest combination of hooking them all together. I could see that the rings were bigger in this flight item than they were in the training item and I wasn't going to be successful at all in getting the big hook around the big and little ring and little hook also around the big and little ring because the little hook was too small to put both rings in. So I let it go. I actually decided at that point to disconnect everything and hook it back up to the original place. The operation would have undoubtedly been simpler in the foot restraints. But again it was a two handed operation and you had restraints - gross restraints - with the waist tethers. You weren't concerned about where the body was going and as expected, the body just had a tendency to rise up as you started doing an operation with your hands, positioning the waist tether attach points

down from where they were attached to your body. Then you just had a natural tendency to drift to a place where the lines and the waist tether attach point to your waist to structure was in a downward direction to your body."

Aldrin was asked whether the big rings were better than the small rings.

Aldrin - "I think the big difference is not the size of the ring as much as it is the big ring has the rigid bar attached to it enabling you to get your hand away from the ring and hold it. With the little ring you've got to get your fingers right on top of it to keep it from flipping back and forth. I think we can deal with little hooks about as well as big hooks."

After completion of the hook and ring evaluation in the water simulation, Aldrin took a 2 minute rest period on waist tether restraints only. This was the pilot's seventh water simulation rest. In flight, Aldrin began his ninth rest period immediately following the hook and ring evaluation. The period lasted 1:31. During this time, the pilot and command pilot reviewed their check list for the subsequent task procedures.

The final group of orbital adapter work tasks included the velcro strip and electrical connector evaluations. The orbital velcro strip evaluation lasted 36 seconds. Aldrin used this task to evaluate the overall work station position with respect to the foot restraints, and also to compare the various simulations in terms of task difficulty.

Aldrin - "Pulling the velcro strips down in one g takes a considerable stretch. In the airplane it's convenient to do and under the water it is fairly convenient. It was as easy to do in zero g as it was in both of the training situations, water and the airplane. So, that kind of a height is accessible from the foot restraints. It is not one where you'd like to do a lot of effort. As I recall, I worked across the velcro strips from left to right and did them all with the left hand except the last one on the right which was the big velcro strip."

Command Pilot Lovell noted that the orbital time line was "four minutes behind schedule" at the beginning of the velcro strip evaluation. The velcro strip evaluation took 30 seconds in the simulation.

In Figure 5-18, Aldrin is seen during an evaluation of the center electrical connector. The adapter work station contained three electrical connectors. The "starboard" connector was not available for the preflight water immersion simulation. Astronaut Aldrin used the fluid connector, also on the right side of the work station panel, to simulate operation of the "starboard" electrical connector. Comments from Aldrin's orbital EVA indicate that he had no difficulty whatsoever with the "starboard" connector while in the foot restraints or on the waist tethers. Table XVI summarizes the performance of the electrical *connector evaluation and details the time intervals for the flight and water simulation . Connector evaluation was performed with tethers only.*

Aldrin describes the overall connector task in his debriefing.

> *Aldrin* - "*The center connector was a good bit more difficult this time than it was in the foot restraints. My body tended to rise up a little bit. Again I think it was more a problem of the bar that was on the locking device. The left connector in the waist tether configuration is a difficult connector to make because the only place you can hold on with the right hand is a good ways away from the connector that you're making. The waist tethers cannot give you enough stability to line up the connector perpendicular to the surface and at the same time let you play with the finger operation to get the locking bar into position so that you can twist it in. This requires pushing against the surface. Now it may be that if you really take pains and cinch up the tethers fairly tight with this special operation that this could be done in an easier fashion. The big point to make here is that two handed operations, where you can hold on to both ends of the connectors and then line them up right in front of you, are simpler to do than just a one handed operation where the other surface is fixed and you now have to position your whole body and everything with respect to the surface. Another factor that I think had a bearing on this is that I'm right handed and this was a left handed connection. I think that tended to make it a little bit more difficult. I would have far preferred to have done that with the right hand. I snuck in a quick evaluation of the right hand connector because we didn't have that on the checklist and it is a fairly easy connector to make. We had them up in the nose, and I wanted to compare that. This airlock connector on the right side is a very neat connector, quite easy to hook and to connect and disconnect. It's a right handed operation. It's a straight twist to disconnect and fairly small force-inward force-required to get it lined up and the alinement marks are simple. There is no prepositioning of the bar required. The alinement to engage the pins seemed to take care of itself. The only thing you have to do is position the connector in the right place and twist and push in at the same time and just keep doing it and you're bound to line them up.*"

Upon completion of the adapter work task in flight, Pilot Aldrin began his work station cleanup. This cleanup task lasted 2:14, during which time Aldrin retrieved his work station camera, retrieved his portable handholds and made a quick evaluation of the one foot restraint configuration. It was at this time that the astronaut discovered the faulty work station camera. Aldrin describes his actions in the debriefing.

> *Aldrin* - "*I hooked the waist tethers to the portable handholds, slapped them on the chestpack and they held fairly well. I took*

one foot out of the foot restraint, moved around a little bit, and then went to picking up the camera. I found that the camera wasn't going to come off, very easily. Incidentally, a little earlier in the operations when I discovered the camera wasn't working, during the rest period I decided to go eyeball to eyeball to the lens to see if I could see it clicking and I couldn't. So, I thought, well, I haven't seen it go before in training, so just to make sure that it is operating, I put my hand on it and couldn't feel anything moving at all. This is fairly early in the operations. So I asked Jim to check the switches to see if they were on. I hit the button again, which should have stopped it, and I checked it again and it wasn't working. So we recycled the procedure. I checked the plugs and at that time I got the definite impression that the camera was warm. I was feeling this through the gloves and there is no doubt that I had the sensation of heat going into my gloves from the camera. I couldn't tell whether this was due to the camera operation and slipping, just not engaging the mechanism, or whether it was due to the sun. This check was done before sunset...

I was trying to do this (camera removal) initially with one foot and when I had a little difficulty, I thought, well gee, let's see how getting the problem done with one foot is going to be. So, I spent a little time trying to do it and decided that the best idea was to put both feet back in again and go back after the task. Finally, by again sticking my fingers into the latching mechanism, I was able to dislodge it and eventually to break it free. I then got the plug undone and attachment on. I attached it to the ELSS."

Aldrin commented on suit heating effects while in the adapter area.

Aldrin - "Just before sunset also, I might add, the spacecraft was held inertial and the sun orientation was such that as it was setting it was shining directly into my buttocks region. The covering on the suit, of course, covered the zipper down to a fairly low point in my back, but below that I could feel a definite warmth along the zipper line, in the crotch area. As I nestled down against the suit, just to check and see how warm it was, I could feel very localized heat and it was obviously coming from the metal zipper. It wasn't objectionable. I didn't notice any total heating resulting from this. There was no work that required your body to be positioned in the suit such that you were forced against this for any amount of time. It tends to confirm the results that we had from Gemini XI that when those zippers are exposed to heat it absorbs a tremendous amount of solar radiation and transmits it directly to you."

Following the adapter work station cleanup tasks, Pilot Aldrin moved out of the foot restraints and moved back to the spacecraft hatch. This movement task took 31 seconds in flight. Figure 5-19 depicts the pilot's position as he "rounded" the adapter pigtail.

Aldrin - "I clipped the umbilical and stood by to maneuver around to the front. We went through the necessary steps to turn the camera off. I don't recall feeling at all tired at this point. Nor was I warm. The sun came up and there was nothing that prompted me to think in terms of changing the flow setting. I just left it where it was and started maneuvering around. I got my feet out of the foot restraints and came around the edge and just before coming around the edge unhooked the umbilical from the pigtail. This was nominal. I got it free from the area and in coming around there was a slight tendency for my head to drift toward the edge. Again I used the pigtail to torque my body down a little bit."

In the water simulation, Aldrin rested for 3:10 immediately after his work station cleanup. This was the ninth rest period in the simulation run, and was followed by an attempt to secure the portable handholds to the ELSS. In the simulation, this rest period and the subsequent restraint evaluation task were prolonged to "eat up time" because the command pilot felt that they were ahead of their flight plan schedule. These prolonged rest and restraint periods were followed immediately by a movement to the spacecraft hatch, which required 64 seconds.

At the hatch area, Aldrin stowed the work station camera and activated the retro adapter camera. In orbit this task took 2:34. In the simulation the same task took 1:33. The time variation can be attributed to the fact that the work station camera stowage was partially simulated in the water mode. Aldrin rested for 45 seconds at this point in the simulation. This was the tenth rest period in the simulation. Immediately following the camera task in flight, Aldrin moved forward from the hatch to the Agena work station. At this point in the flight, film is again available for comparison. In orbit the movement took 1:14. In the simulation the same movement took 1:05.

TDA Work Station Tasks - In both orbital and water simulation, Aldrin began his TDA work tasks with an initial placement of the pip pins and portable handholds carried on his chestpack from the adapter. In the water simulation, Aldrin spent 2:10 on this initial placement task. He then rested for a scheduled 2 minutes. In his orbital EVA, Aldrin spent 2:13 on basically the same placement task. At the end of this time, the pilot requested a rest period. He rested 3:07. This was Aldrin's tenth orbital rest period.

It should be noted that this was one of the few times Aldrin requested a rest period. Using the onboard voice recording as an indication, a note of "tiredness" was detected as Aldrin requested this rest. It appears that skipping the rest periods at the spacecraft hatch area proved unwise, and the cumulative effect of movement, camera placement and another movement caught up with the pilot as he began his first TDA work task. Subsequent biomedical analysis tends to substantiate this. Variation in the task procedure between the orbital and simulation modes could also partially explain the marked separation between the work load rates during this final phase of the umbilical EVA.

The pilot began his eleventh orbital rest period immediately after this second TDA work station task, Group B. This orbital rest lasted 1:54. From the onboard voice transcript it appears that Aldrin did not really rest during this period, but was working on the TDA work station. In the simulation, Aldrin's final rest period followed the TDA work task and lasted 1:55. This was the pilot's twelfth rest period in the simulation.

The final TDA work station task group (Group C) in space varied slightly from those in the water simulation. Here again, the simulation training allowed the astronaut to streamline his orbital task and make the most of each evaluation. The variation between the flight and simulated performance of this task group reflect this advantage. In the simulation, Aldrin moved aft from the Agena to the spacecraft hatch following the TDA work task. This movement took 1:04. Aldrin retrieved the retro adapter camera and handed it into the command pilot, making use of the portable handrail. He also handed in the Apollo torque wrench, which he had retrieved from the TDA work station. This took 1:40, after which Aldrin ingressed the spacecraft and stood erect in the cockpit. Ingress required 27 seconds. Aldrin proceeded immediately to detach and jettison the portable handrail (28 seconds).

The final task in the simulation was hatch closure preparation lasting 29 seconds. During this time Aldrin checked the hatch seal for debris, deployed the hatch holding device, and positioned and recovered his umbilical. Of these three final subtasks, only the umbilical recovery was actually performed.

During the orbital umbilical EVA, Aldrin was asked to observe the left hand spacecraft thruster system at the end of his last TDA work station task group. Aldrin made this observation while completing his work station cleanup task. The entire task took 41 seconds.

Following the cleanup task, Aldrin moved from the TDA to the spacecraft hatch. This movement took 51 seconds. The pilot stopped on the portable handrail and performed the optical surface evaluation. This evaluation was performed at 4:55 (ET) in the water simulation. Aldrin spent 55 seconds attempting to clean the command pilot's hatch window. Aldrin describes this operation in his debriefing.

> *Aldrin - "I wiped off the window on Jim's side. The handkerchief came out quite easily. There wasn't any particular tendency to have it float away. This is obviously a one-handed operation. I held onto the handrail again with an arm and a hand. In other words, the arm was along-side of it and then somehow I used my feet against the handrail because it went back along the spacecraft. This gave me enough action with an elbow against the side of the spacecraft, so that I could push against the window fairly well and was in a good position to rub. I could see that I was obviously rubbing the film off the surface. I guess I got it off, except for that one square that heated up."*

Ingress required 1:24 in flight. Aldrin performed a visual thruster checkout task, and then jettisoned the portable handrail. Handrail jettison required 44 seconds.

Aldrin's final tasks prior to hatch closure were the same as in the water simulation. The pilot recovered and positioned the umbilical in the hatch area, deployed the hatch closing device and checked the hatch seal for debris. He commented that the seal was clear except for some flecks of dust. Preparation for hatch closure required 1:05.

The preflight water immersion simulation of the Gemini XII umbilical EVA established a target flight plan for the actual orbital EVA mission. The simulation was not intended to establish a definitive time interval for individual tasks. The resulting orbital versus simulation tasks, therefore, varied in time duration. Figure 5-20 is a task time comparison of the orbital and water simulation modes. It can be seen from this comparison that in the early portion of the EVA most orbital tasks were longer than the simulation mode. Toward the end of the flight, the time lines became more consistent but deviations of the tasks were still apparent.

The astronaut's natural tendencies to proceed with caution in a new environment could easily explain the increased time for the orbital tasks. In his water simulation, the pilot had practiced the tasks many times and this environment during his final preflight simulation was more familiar. Certain of the preflight water simulation tasks were longer than the orbital mode. In these tasks, such as the work station preparation and positioning tasks, Aldrin spent extra time evaluating the best possible mode of task performance. His objective was to streamline these tasks so that he could spend more time on the important task evaluations in flight. The total time line in space was only slightly longer than the water simulation flight plan.

Figure 5-21 presents a summary of the comparison of the time intervals for the major task categories of orbital and water simulation modes. It is interesting to note the extremely close comparison for the work station tasks. There was a relatively large difference between the orbital and simulation modes for the experiment support category. Absence of high fidelity hardware in the simulation forced the astronaut to "fake" or completely omit certain parts of these tasks. This greatly reduced this simulation time interval.

Since one of the prime objectives of the Gemini XII umbilical EVA was to evaluate restraint modes, it is significant that Aldrin spent more time in orbit than in the simulation on the positioning and restraint category. Camera placement and retrieval tasks were basically the same in space as they were underwater. The time deviation resulted from the mechanical difficulty with the work station camera during the orbital mission. Aldrin used extra time on this task attempting to correct the malfunction in space. In the simulation he noted a similar problem but continued on with the time line.

The close agreement between the flight and simulation for movement tasks is also important. This data tends to substantiate subjective observations and measurements that motion in space and water simulation are closely related but are indeed slower than motions simulated in the zero gravity aircraft. Comparison of the rest periods shows the total orbital rests to be longer than the rest periods in the simulation, even though there were a greater number of rest periods in the water simulation. Although the flight rest periods were longer, they were more unevenly spaced throughout the mission. At the beginning of the flight EVA there appeared to be too many rests. Towards the end of the mission, it appears that more rests could have been used.

In general, comparison of task time duration between space and water simulation was in close enough agreement to permit first order correlation. However, the disparities noted were of sufficient magnitude to preclude uniquely determinant human factors information to be developed. This factor should be strictly evaluated when future experiment planning is undertaken.

5.3 - WORK LOAD COMPARISON - The performance of the Gemini IX and XI EVA emphasized the question of the exact determination of the effects of weightlessness on human performance. Life support equipment designed for the Gemini missions had, for the most part, performed according to design specifications. However, it appeared that these design specifications did not adequately encompass the range of the Gemini EVA task complement. The close approximation of water immersion simulation to the kinematic aspects of the Gemini IX-XI EVA supported the premise that extension of the simulation to measurements of certain physiologic parameters would be warranted.

The work load measurement techniques evolved along with the simulation techniques, starting with the initial preflight simulation run of the GT-XII EVA. The initial instrumentation system utilized the Gemini biomedical harness and sensors. RF interference precluded the use of this system and the ultimate technique employed the biomedical harness developed for the Apollo program. This system was utilized successfully throughout the subsequent simulation program and the results presented. A functional flow diagram for the instrumentation system was shown in Figure 2-1. Hardwire sensing lines were run through a modified dual-umbilical line, which served a multipurpose function: (1) air intake and exhaust, (2) instrumentation, and (3) two-way communications.

Table XVII details the components of the final version of the instrumentation system used during the simulation. Physiological variables monitored were body temperature, respiration rate, and EKG. Information pertinent to the suit inlet flow and sampled gas measurements were made on a discontinuous basis in tabular form. Measurements were made of heart rate, respiratory rate, body temperature, suit carbon dioxide and oxygen concentration.

Breathing quality air (water pumped) was supplied to the G4C full pressure suit at 8-10 cfm at a pressure of 3.7-4.0 psi above the ambient pressure relative to the depth at which the subject was working. This pressure gradient was controlled by means of the suit-mounted relief valves described previously. The oxygen concentration in the exhaust gas was determined by a Beckman E-2 oxygen meter with the Beckman model D-1 serving as an auxiliary monitoring backup. Carbon dioxide concentration in the exhaust gas was primarily determined with a Perkin-Elmer analyzer (Apollo system) with a Liston-Becker meter serving a monitoring backup function. Respiration rate was determined from the output of an impedance pneumograph. EKG readings were accumulated using skin mounted electrodes. Body temperature was measured by means of an ear thermocouple for the astronaut and by a rectal thermistor probe for the ERA subject. Biomedical measurements were made under the direction of Dr. E. L. Beckman, MSC, with support of Cdm. L. J. Greenbaum, MSC, NMRI.

Initially, metabolic rates were calculated by the de Weir technique. Later, estimates of the metabolic load were made by means of preflight ergometric-heart rate correlations. These later determinations proved more useful for simulation-space performance comparison. Particular attention was centered on determining the effectiveness of the rest periods interspersed throughout the time line. Also, a determination of the production and accumulation of carbon dioxide in the full pressure suit was made since there was some evidence that this may have been the limiting factor on the Gemini XI. To assess this factor, air with 5.0% carbon dioxide concentration was metered to the ERA subject during one of the checkout runs for a short period and appropriate measurements were made.

The main purpose of the physiological measurements during the simulation was to develop a biomedical baseline of sufficient credibility to permit real-time monitoring of the astronaut's flight performance. These data were used to establish a heart rate limit for the flight performance. The limit established corresponded to a work load of 2500 BTU/HR for slowdown and approximately 3000 BTU/HR for cessation of work.

Concommitant with the development of these physiologic guidelines, it appeared that significant benefits could be derived from the comparison of the preflight biomedical data with that accumulated during the flight. It was recognized that direct comparisons would be difficult since last minute changes to the flight plan and flight contingencies could arise which would significantly alter both the duration and sequential ordering of the EVA tasks. These changes proved to be of a minor nature and, for the most part, the time line resulting from the final preflight water immersion simulation run was followed during the flight.

The NASA primarily utilized the physiological information from the simulation for crew monitoring purposes and to evaluate postflight responses. The following instrumentation was used during umbilical EVA: one electrocardiagram lead, one respiration rate lead, and one lead for suit pressure. In the later flights, IX-XII, the pilot monitored his own suit pressure and this measure was deleted.

Figure 5-22 presents the results of the measurement of physiological parameters of the Gemini XII EVA. As mentioned previously, problems developed as the EVA task line became more complex. Results from GT-XI indicated that excessive thermal loads due to the functioning of the ELSS and carbon dioxide buildup due to high respiration rates may have compromised the performance. Direct determination of these factors was not possible for the flight since data on thermal conditions and carbon dioxide level was not collected. Also, no direct measurement of metabolic load was made.

In the absence of direct calorimetric measurements, the NASA relied on extrapolation of the preflight and postflight ergometric measurements of the pilot to estimate work load levels. Recognizing the factors involved, the feasibility of using heart rate as the primary indicator of work load was investigated. Physiologic, psychological, as well as pathological factors, play an important role in determining the response of the heart rate to various work loads and work rates. Several factors mitigate these considerations (1) the specific work load determination did not require generalization from a small sample population to a large sample population, in fact, a preflight and postflight calibration was done for each pilot, (2) the heart rate parameter was one of the two existing for the measurement, the second parameter, respiration rate-energy correlation was considered but rejected due to voluntary control factors and equilibrium response considerations.

Heart rate-work load correlations were determined for each EVA pilot by bicycle ergometry. During these tests, the astronaut performed a measured amount of work on a bicycle ergometer at normal pressure and temperature. Pressure suits were not worn during these tests. The work load was incrementally increased, (+16) watt for each one minute increment and heart rate, respiration rate, blood pressure was measured on a continuous basis. Samples of expired gas were periodically collected for subsequent analysis. Figure 5-23 presents the results of the preflight ergometry tests. The data from these tests were converted to the oxygen utilization curves given in Figure 5-24.

Two methods were employed to determine the work load of the GT-XII task line during the water immersion simulation; the deV. Weir method, and heart rate-work load correlation using the preflight ergometry. In the deV. Weir method, work load is determined by measuring the percentage of oxygen in the expired air and determining the respiratory quotient (RQ). In direct calorimetry, utilizing open loop respiratory gas analysis, e.g., the Douglas-Haldane technique, the energy output is most simply determined as the product of the volume of expired gas by the caloric value of the expired gas. Generally, formula (1) can be used to determine the metabolic output E-kg.cal.

$$(1) \quad E = 3.941 + 1.1\ RQ$$

J. deV. Weir has proposed a modification of the above to account for the precise O_2 metabolizing mechanism involved. The deV. Weir *form was used during this experiment and is given in equation (2), using a standard protein correction (12-1/2%).*

$$(2) \quad \Sigma E = (3.941)\, V_{o_2} + (1.106)\, V_{co_2} - (\text{protein correction})$$

Since one liter of expired air contains $O_e/100$ liters of oxygen, where O_e is the oxygen concentration, the (V_{o_2}) oxygen consumed is given by (3).

$$(3) \quad V_{o_2} = \left[1 + (1 - (RQ))\, V_{o_2}\right] O_i/100 - O_e/100$$

O_i = *oxygen concentration in the inspired air*

Therefore, equation (3) may be given by (4).

$$(4) \quad V_{o_2} = (O_i - O_e) \,/\, (79.07 + 20.93\,(RQ))$$

Combining equation (2) and (4)

$$(5) \quad E^1 = (O_i - O_e)\,(3.941 + 1.106\,(RQ)) \,/\, (79.07 + 20.93\,(RQ))$$

Figures 5-25 and 5-26 present the results of the work load determination by this technique, of the simulation runs by the astronaut, Col. E. Aldrin. Table XVIII summarizes the results of the determination of the work rates for Aldrin's simulation run. Figure 5-27 and 5-28 and Table XIX present comparative data from the simulation runs performed by the ERA subject, including the effect of altered carbon dioxide concentrations.

While the most consistent indicator of stress response proved to be respiratory frequency, when compared to the caloric changes computed by the de V. Weir technique, there appeared to be a great disparity between the actual level of activity and work load computed in this manner. It can be seen in Table XVIII that the oxygen utilization method indicates that maximum work levels occurred at periods of low activity (rest) while periods involving maximum suit-flexure and force output yielded low work levels.

The disparity between the calculated work load, body temperature, and expired CO_2 concentration was even greater. These, however, can be readily explained. The body temperature was measured at one point only (rectally for the ERA subject, externally behind the ear for the astronaut). No reliable measure of metabolic activity has been obtained so far using single point temperature measurements since the relationship of the time response of temperature to work load increases is exceedingly complex. CO_2 measurement during the simulation proved unreliable since measurement took place at the exit of the exhaust line.

No effective determination of the system time constants could be made due to the variability of the system and since absolute control of water leakage in the system could not be controlled (CO_2 is readily absorbed in water). This was due, in part, to the unavailability of the space suit until close proximity to the test.

Further, there was no comparative measurement of work load in space. In the absence of direct measurement of metabolic load in space, the NASA placed maximum reliance on electrocardiagram and impedance pneumogram measurements of the astronaut during the EVA. Severe limitations were recognized in the use of this information as mentioned previously. NASA indicated that the accuracy of these data should increase with increased oxygen utilization, and since the area of consideration was at high relative work loads, any errors would tend to elevate the heart rate for a given condition. This would yield a margin of safety when using the heart rate-ergometry correlations for a slowdown and stop indicator.

Data from preflight altitude chamber runs, correlations from results of previous flights, and the initial results of the underwater simulations served to derive a quantitative measure of the work expenditure. NASA concluded that the use of heart rate and respiration rate data supported by continuous onboard voice contact proved to be an extremely important and reliable method for real-time monitoring of the crew activity particularly when coupled with a complete knowledge of the tasks involved.

Using the foregoing as a basis for comparison, Figure 5-29 was developed which details the cumulative work load of the time line for the flight and simulation. This relationship was derived by developing an expression for the relationship between heart rate and work load from the preflight ergometry for the pilot. The figure was developed by using this relationship and the heart rate versus time for the flight and the simulation. The curves were developed by applying the heart rate-ergometry relationship and integrating with respect to time. This technique yielded a much closer correlation between observed activity level and work load.

This correlation is not intended as an absolute determinate of work rate but, rather, is intended for comparative purposes. It does, however, offer distinct advantages for tasks of the nature of the GT-XII EVA tasks. Conventional closed and semi-open ventilatory measurement techniques generally require considerable response time for the measurements to reach equilibrium (from 1-5 minutes). This time period is generally greater than the steady state task time of the individual tasks and, therefore, direct analysis of oxygen utilization data is exceedingly difficult. Heart rate measurements, on the other hand, respond rather rapidly to changes in work load.

Comparative evaluation of the heart rate data indicates an average 35% greater heart rate for the flight. This may be due to several identified reasons. First, there is the effect of the variation of ambient pressure and breathing medium on heart rate-ergometric correlation. This effect is probably related to the density of the breathing gases but may also be related to variation in alveolar oxygen transport. Figure 5-30 presents the results of parallel research which indicates the effect of variation of gas density.

The second major factor causing the difference in heart rates noted is probably the most important. In space, the astronaut was subjected to a vapor saturated oxygen environment with limited heat transfer capability. In the simulation, the water acted as an infinite heat transfer sink. Further, the thermal load characteristics differed greatly. Previous research has generally identified the effects of changes in the thermal environment on heart rate, Figure 5-31. In this program, a standard work level rest cycle was obtained and the thermal load characteristics were varied. It can be seen that increasing thermal load tends to increase the heart rate for a given work level and this relationship increases with time.

A third factor is that of psychological effects on the heart rate due to operations in the space environment. If psychological involvement were a first order factor, the heart rate in the initial phases of EVA would be greater in space than in simulation with a gradual tapering off if no problems were evidenced. Analysis of data shows the opposite. The period where a large psychological involvement was thought to occur was during the time of the messages to Houston and even in this, there is strong reason to believe that the astronaut was engaged in moderately strenuous work of placing pennants on the ELSS.

There is other parallel research which supports the use of the single parameter determination of energy cost for calibrated individuals. Malhorta et.al., have reported on the feasibility of using pulse rate during work as a measure of energy cost. Studies were made using bicycle ergometry with work loads varying between 50-600 kg-/min. Cross-correlation of the results with oxygen uptake methods was made and regression correlation lines were calculated. While a significant difference was found in the coefficient of variation between subjects, a linear correlation was obtained between the pulse rate and energy cost for all subjects. Typical results of this research study are given in Figure 5-32.

Figure 5-32 also presents the results of a similar study by N. L. Ramanathan, <u>Reliability of Estimation of Metabolic Levels from Respiratory Frequency</u>. Ramanathan has demonstrated the reliability of estimating task energy cost for relatively high energy metabolism. A correlation of $E\,(\text{kcal/min}) = -3.06 + 0.198\ RF\ (\text{no./min})$ was obtained between energy consumption and breathing rate. This correlation was highly significant ($P<0.01$) with a correlation constant of 0.93 and standard error of 0.46 kcal/min. These data are included to indicate the factors involved in using the heart rate-ergometry correlation technique. A more extensive research program is required to evaluate the exact numerical correlation factors involved.

Table XX presents the data derived through heart rate-ergometry correlation and compares the results of the space performance with the simulation. These results are depicted in Figure 5-33. It can be seen that, in most cases, the energy costs of the tasks were greater for the space performance. Figure 5-34 presents the same results reconfigured to show relative rates of energy expenditure, since the task times were also generally greater for the orbital case. The results of this comparison show that there is a relationship between simulation and space performance. The ratio of energy cost between space and water simulation averaged approximately 1.57 and varied between 0.69 and 3.44.

Prior to this study it had been considered that drag effects and other associated problems would result in a higher energy expenditure for a given task in the water immersion simulation than in actual space performance. Since this has been shown to be not necessarily true, it is important to properly identify the elements of the simulation and the effect of each on the energy cost in task performance. These elements include: viscous drag (d); gravity effects (g); buoyancy effects (b); planing effects (p); and hydrostatic effects (h). These elements may increase or decrease the energy cost (α) for any given task. The relation of the energy required for task performance in simulation (E_W) and in space (E_S) takes the following form (6).

$$(6) \quad E_W = E_S \pm \alpha_d \pm \alpha_g \pm \alpha_b \pm \alpha_p \pm \alpha_h$$

If the agregate of the α terms is negative for a particular task the task requires less energy in the simulation than in space i.e. certain factors in the water have acted in such a manner as to reduce the total energy expenditure for that task. Since the suit pressure is regulated at the waist level, portions of the suit above this level have a greater differential pressure than in space while portions below this level have a lesser differential pressure than in space. As an example, tasks that involve arm and hand motions result in a positive α_h term for the upright subject and a negative α_h for the inverted subject. In like fashion the other elements can exhibit both positive and negative effects.

The results of the Gemini XII analysis shows $E_S > E_W$ for the majority of the EVA. Therefore, the combination of the elements acted to reduce the energy cost of these specific tasks in the water over the cost of the same tasks in space.

The terms ($\pm \alpha_d \pm \alpha_p$) are related to the subject's motion in the water medium and can be explicitly derived as a function of the velocity vector and body attitude of the subject. In general, the specific terms of the relationship can be uniquely determined for one suit and body configuration, i.e. changes in the body configuration affect the drag coefficient of the whole body as well as the individual limbs.

The predominating element as the velocity increases is the α_d term. This relationship can be seen from Figure 5-35, which presents calculated values of drag for several suit attitudes. For the Gemini XII tasks the velocities of movement were generally < 0.5 ft./sec. and the number of movements was small in consideration of the total EVA time. Therefore, the terms of (6) for the Gemini XII EVA are approximately given by (7).

$$(7) \quad E_W = E_S \pm \alpha_b \pm \alpha_g \pm \alpha_h$$

King et.al., has calculated the gravitational work for limb motion of man unencumbered by a pressure suit. Gravitational work expressed as percent of muscle work ranged to approximately 15% in the studies. Translating these factors to pressure suited man would tend to reduce the gravitational work factor since the work required to overcome the pressure suit is far greater than the work required to move the limbs unsuited. Generally the α_g element is a positive term.

In summary, although the water immersion simulation of the Gemini EVA was not intended to produce data for purposes of comparison with space flight EVA, there was, in fact, much data available from which comparisons have been made. There are also elements which have been identified and which are unresolved as to their contribution to energy cost. These unresolved elements are the hydrostatic effects (α_h) and the buoyancy (α_b) term both total body and specific limbs. Hydrostatic and buoyancy effects cannot now be evaluated for the Gemini XII simulation and indeed would be extremely difficult to determine for subsequent simulation since the suit buoyancy characteristics change relative to time during any particular run. It is important, however, to determine the range of this effect in future work.

In addition, the effects of heat load and breathing gas density must be evaluated. A determination of these factors can be made experimentally and a more exact relationship governing the comparison can be determined. Until this is done the cumulative work loads determined by preflight ergometry should be used as a relative comparison parameter.

<u>5.4 - EVALUATION OF TASKS BY CATAGORIES</u> - Table XXI is a compilation by categories of the EVA tasks identifying specific task objectives. The first category, EVA evaluation tasks, are tasks designed to directly evaluate man's performance in the extravehicular

environment. The design of these experiment-tasks was intended primarily to yield subjective data. Comparative film and motion analysis was applied to these tasks where possible.

EVA Evaluation Tasks

The objectives of the EVA evaluation tasks included the determination of restraint modes, suit mobility, torque capability and the feasibility of simple maintenance tasks. The EVA evaluation tasks were comprised of various subtasks. Table XXII lists the task evaluation objectives for the various EVA subtasks.

Restraint Evaluation - Restraint evaluation comprised the performance of various representative EVA tasks using foot restraints, adjustable waist tethers and a system of portable pip pins and handholds for restraint positioning. Both portable handholds and pip pins were constructed with large rings to accept the waist tether quick release mechanism. The astronaut was able to evaluate many different restraint positions in a relatively short time period using the pip pin arrangements.

In Figure 5-36, Astronaut Aldrin is shown placing a restraint attached to a pip pin into the star receptacle on the Agena work station. Figure 5-37 shows the astronaut adjusting his positioning with a restraint attached to a portable handhold. Stationary attachment points were also used in restraint evaluation. These took the form of small rings attached to the target docking cone and a single stationary ring on the "nose end" of the portable handhold. These supplied ample attach points for tasks such as the Agena tether, S-010. The first rest period, on waist tethers, was performed while attached to these stationary positions. Similar attachment points were supplied on the adapter work station. Astronaut Aldrin used these stationary rings almost exclusively during his "waist tethers only" adapter restraint evaluations. The portable handholds, while showing some merit on the TDA, proved inadequate in the adapter work station. Aldrin noted that only minimum torquing forces were required to break the handholds free from their positions. The TDA handhold positions proved adequate primarily because no excessive torques were placed on these units. In most cases, it appears that the TDA waist tether configuration aided in maintaining the pilot's gross position on the Agena, but was not particularly useful to react torques. During work tasks the astronaut employed his arms to reduce the forces transmitted to the tethers and portable handholds.

Figure 5-38 shows the effect of restraint modes for both the adapter and TDA work station tasks. The restraint modes are indicated by the legend at the upper left of the figure. The cross-hatched areas indicate rest periods. Number (1) indicates task performed by the astronaut while he had one or both feet in the molded foot restraints. The tasks performed while in the foot restraints were restricted to the adapter where the foot restraints were located. While in the adapter, the astronaut repeated the task performance with waist tethers only. Comments from the astronaut indicated a strong preference for the foot restraint mode.

The foot restraint mode required slightly larger performance times than the waist tether mode both in space and in the simulation, however, the rate of energy expenditure was significantly less. This contradicts the results previously described for the Gemini IX AMU donning task. A fixed restraint position such as evidenced with the foot restraints permits a greater envelop of operation in the suit, particularly for two-handed tasks, while decreasing the level of energy expenditure.

The Gemini suit afforded easy control of the rest position of the suit due to the "stiff" leg and torso components. In later space suit versions, having greater mobility, this will not be true and extra energy will need to be expended to keep the astronaut in the proper orientation for work tasks for fixed restraint modes.

The restraint modes evaluated while on the TDA included two waist tethers, one waist tether, and no restraints. There was a greater variation between space and the simulation for these tasks. The results of the evaluation of restraint modes for the different work station tasks is given in Table XXIII.

Suit Mobility Evaluation - The major suit mobility evaluation was performed in the adapter section while the astronaut was restrained by the foot restraints. The pilot performed a task in which he leaned backward away from the spacecraft while in the foot restraints. Figure 5-39 demonstrates two aspects of this task in which the pilot attempted to determine the angle and radius of action of his G-4C space suit. In general, suit mobility evaluation was a continuous aspect of the overall task evaluations.

The limb flexure analysis derived from film analysis for the lean back task in the preflight and postflight simulation is presented in Figure 5-40. During the flight, the pilot commented that the lean back task was more difficult than in the preflight water simulation. He noted in this postflight run that the task was very much like that performed in the orbital mode. The increased force requirements for the flight and postflight simulation were caused by the use of the more rigid extravehicular space suit (FPS). The extra protective layers caused an increased suit rigidity. This factor required the astronaut to expend extra energy using the EV suit over that experienced in the preflight simulation with his training suit.

Torque Tasks - The evaluation of the astronaut's ability to exert torquing forces was performed in the equipment adapter and Agena work station. Torque capability of a restrained and unrestrained astronaut is considered of prime importance for future space missions. The adapter work station torque evaluations were performed on a fixed bolt configuration located at the bottom center of the work panel. In both the flight and simulation modes, Pilot Aldrin evaluated clockwise and counterclockwise torquing operations. Aldrin first performed the adapter torquing operation while in the foot restraints. He then attached his left and right waist tethers and re-evaluated this task with tethers only. Table XXIII summarizes the time allocated to torque evaluation and the energy expenditure involved for the orbital and simulation modes.

The astronaut used a special torque wrench for the Agena work station portion of his torque evaluation. This tool was manually adjustable and designed to "break free" if the set value of torque was exceeded and was designated the Apollo torque wrench. The Apollo torque wrench shown in Figure 5-41 employed a male "key type" drive. The bolt receptacle on the Agena work station was fixed mounted in a torque box.

The adapter torque wrench malfunctioned during both the flight and the simulation torque tasks. In both cases the visual readout gauge failed. It is also worth noting that in the water simulation, Aldrin broke the "fixed bolt" free when using the maximum torque setting on the wrench.

Quantitative data on either the flight or simulation cannot be derived due to equipment failure. However, Astronaut Aldrin noted in his debriefing that any torque task found practical in the water simulation would also prove practical in space.

Maintenance Tasks - Those tasks, specifically designed as an evaluation of proposed future space maintenance, included bolt removal and replacement, electrical and fluid connector operations, cable cutting operations, hook and ring connection, and the velcro strip evaluation. The initial camera placement and the work station preparation and cleanup tasks were also included in this task category.

The first camera placement task was an evaluation to determine an optimum mode of camera handling. The results of this evaluation showed that camera placement and retrieval was optimized when the pilot utilized a semi-unrestrained positioning technique requiring only the use of his free hand to place his body in the proper relative position.

Maintenance task evaluation was performed on the Agena work station. An electrical connector, similar to the connector in the adapter work station, was mounted on the side of the Agena work station panel. Aldrin noted that he found no problem in connection or disconnection of this unit in his preflight or orbital EVA.

In general, the task performance was very similar, both from a time and work level basis. The astronaut did not experience any difficulties in performing the tasks as prescribed. Work loads and time allocations were successfully predicted in the simulation. The evaluation of restraints proved to be highly amenable to water immersion simulation.

EVA Support Tasks

Camera Placement and Retrieval - Astronaut Aldrin's first umbilical EVA camera placement task in both orbital and simulation time lines was categorized as an EVA evaluation task. All subsequent camera tasks were entirely support tasks designed to produce a 16 mm color film record of the umbilical EVA. Except for the camera mechanism failure in the adapter section, Aldrin noted no problem with the camera placement tasks in orbit. He did comment that his initial camera placement seemed even easier in flight than it had been in the simulations. This fact may certainly have been the result of training experience.

Movement - Movement along the spacecraft and from the spacecraft to the Agena target vehicle in previous Gemini missions was considered an important task objective. For the Gemini XII EVA mission, a system of motion aids was designed to expedite this movement. The utilization of the motion aids provided increased time for the subsequent EVA evaluation tasks. Movement from the spacecraft hatch area to the Agena was aided by the installation of the portable handrail, Figure 5-42.

Analysis of the film record from the water simulation shows this forward movement to have the greatest velocity among all the gross movement tasks of the GT-XII umbilical EVA. The velocity of this movement was approximately 0.3 feet per second. This is less than the limits established for drag-degradation effects, 0.5 feet per second. The movement from hatch to TDA was 10 seconds longer in flight than similar movement in the simulation. From analysis of the flight film, the motions appear to be identical, although the velocity was slightly less than that of the water simulation. It is significant to note that even though the velocity in the simulation was higher and the time shorter, that the energy cost was higher for the orbital movement task. This further substantiates the absence of perceptible drag effects in the water simulation for movement tasks of velocities under 0.5 feet per second.

Rests - Figure 5-43 compares the rest periods for the flight and water simulation modes. Cross-hatched areas on the figure indicate the rest periods. The single reversed cross-hatch area indicates the duration of the water simulation rebalance break. A comparison of the individual rest periods, from a time and energy cost basis, is given in Table XXIV. The most significant variation between space performance and simulation is the number and frequency of rest periods. There were twelve rests in the water simulation and only eleven in the flight. The total time of the rest periods, however, was longer in flight than in the simulation. Although the total orbital rest time was in excess of the simulation time, it appears that the rest periods during the simulation were better spaced, thereby contributing to minimum energy expenditure.

Two flight rest periods, numbers (4) and (10), are of particular significance. Rest period (4) was particularly long, yet the rate of energy expenditure increases rapidly through the half of the duration. Although this time period was designated as a rest, Pilot Aldrin used this time period to deliver messages to the world. The detailed activity during this rest period was discussed in a preceding section. Analysis has shown that this rest period included periods of relatively high physical activity. The energy cost is probably misleading, however, since mitigating psychological factors may be involved. Mission Control was warned of the increase in heart rate to the 140 beats/min. level by the telemetry readout and Astronaut Aldrin was advised of this increase. In the middle of this rest period the pilot was advised to slow down his activity and complete the period in a resting position. The result of this slowdown was evidenced in the decreasing energy expenditure rate towards the end of the rest period.

Orbital rest period (10) was also an extended rest period. Reference to the cumulative energy expenditure line shows a marked increase in the rate of energy expenditure just prior to this rest period. For an explanation of this rate increase and the subsequent extended rest period, the following correlation between the simulation and orbital time lines is postulated. Immediately following the adapter work station tasks in the simulation, Aldrin moved to the spacecraft hatch. At this point he executed a camera change and rested for 45 seconds. After this rest, Aldrin moved forward to the Agena work station to begin his TDA work tasks. Following his first work station task group, the pilot took his scheduled 2 minute rest period. From the voice record, it does not appear that the astronaut was excessively "tired" at this point. There was a slight increase in energy expenditure during the movement forward from adapter to Agena. In contrast to the performance in the simulation, after Astronaut Aldrin completed his orbital adapter work tasks, and moved to the spacecraft hatch, he did not take advantage of a rest period. Instead, he made his camera change and activation and continued immediately to the Agena work station. On the Agena, Aldrin immediately began his first TDA work task. After approximately the same task time interval as in the simulation, the pilot completed this work task group and "requested" a rest period. From the voice recording it appears that the astronaut was ready for this rest. This was the extended duration rest period (10). It lasted 3:07 and was the longest actual resting period in either the orbital or water simulation modes.

In summary, the rest periods generally proved successful in maintaining a relatively normal energy expenditure for both the flight and the simulation. The only difficulty pertaining to interpretation of the rests is that the astronaut performed minor tasks during his resting sessions.

Experiment Support Tasks

The final task category includes those tasks which were not directly related to EVA but which required support by the EVA astronaut. The tasks included the Agena tether and S-010 activation, and the retrieval of the GLV strips. Figure 5-44 presents the comparison of the experiment support task category.

The Agena tether activation was a preparation for the gravity gradient experiment later in the Gemini XII mission. The Agena tether task took 40 seconds more in flight than the same task in the simulation. The energy expenditure was also greater for the orbital mode. The increase was due to time the astronaut spent evaluating the loose "toadstool" on top of the docking bar. This in itself would not appear to justify the increased energy expenditure. The astronaut's motions were essentially the same for both modes of this tether task. The difference in energy cost could be attributed to either variations induced by the *simulation or actual undefined variations due to work in a gravity free environment. The difference noted could easily be attributed to this later factor as discussed in the preceding section.*

The remaining tasks, the S-010 activation and the GLV strip removal, will not be discussed since the actual S-010 hardware was not available for the simulation and since the GLV strip removal proved to be negligible from a time and energy standpoint.

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Positioning/Restraint	Standup familiarization	Standing in spacecraft hatch	0	0	:50	:50	Command pilot marks beginning of standup familiarization (8 minutes into umbilical EVA)
Camera Placement-Retrieval/Film Change	Selection of optimum camera placement mode	Standing in spacecraft hatch, leg tethered	:50	:50	1:50	:60	Pilots' tethered position in cockpit was simulated in this time line. Pilot attempted to "brace himself" in the cockpit.
	Selection of optimum camera placement mode	Standing in spacecraft hatch, untethered	1:50	1:50	2:55	:65	Pilots' body drifted 80% out of cockpit while attempting camera installation untethered
Positioning/Restraint	Preparation for camera placement evaluation outside hatch area	Spacecraft exterior, hatch area	2:55	2:55	3:20	:25	Pilot positions his body outside and over the spacecraft hatch - parallel with the fore-aft axis of the spacecraft.
Camera Placement-Retrieval/Film Change	Selection of optimum camera placement mode, spacecraft exterior body position	Spacecraft exterior, hatch area	3:20	3:20	4:25	:65	
Positioning/Restraint	Preparation for rest on handrail	Spacecraft exterior, on handrail	4:25	4:25	4:35	:10	Pilot moves from retro adapter camera position to handrail using both hands to maintain a resting position with his torso and legs extended over command pilot hatch.
Rest (1)	———	"	4:35	4:35	4:55	:25	
Optical Surface Evaluation	Attempt to clean s/c window with wiper cloth	"	4:55	4:55	5:50	:55	
Rest (2)	———	"	5:50	5:50	6:20	:30	

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Positioning/Restraint	Umbilical extension prior to forward translation to ATDA	Spacecraft exterior, on handrail	6:20	6:20	6:30	:10	Pilot simulated this task since umbilical was already extended
Movement	Translation along portable handrail to docking bar	"	6:30	6:30	7:01	:31	During rest and umbilical extension tasks pilot maneuvered partially up handrail. At beginning of movement task pilots position was forward of hatch.
Positioning/Restraint	Evaluation of tether dynamics	Spacecraft/ATDA interface	7:01	7:01	8:37	1:36	
"	Preparation for Agena tether task.	"	8:37	8:37	8:57	:20	
Agena Tether	————	"	8:57	8:57	10:37	1:40	Pilot tethered to ATDA rings with both waist tethers.
Positioning/Restraint	Repositioning on ATDA prior to S-10 deployment	"	10:37	10:37	12:07	1:30	Pilot repositions both waist tethers to S-10 area locations.
Communications	————	"	12:07	12:07	12:32	:25	
S-10	————	"	12:32	12:32	13:27	:55	Pilot tethered to ATDA rings with both waist tethers. S-10 task simulated because of low fidelity mockup characteristics.
Positioning/Restraint	Repositioning on ATDA prior to velcro strip removal	ATDA work station	13:27	13:27	14:42	1:15	
ATDA Work Station Preparation	Initial pip pin placement	"	14:42	14:42	18:09	3:27	

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Rest (3)	———	ATDA work station	18:09	18:09	19:49	1:40	Command pilot notes"at end of rest period, flight plan time is 28 minutes into day-light period"
Positioning/Restraint	Preparation for translation aft to hatch	"	19:49	19:49	22:49	3:00	Pilot notes that hook up of waist tethers to ELSS was made difficult because of large "D" ring catching on pip pin.
Movement	Translation along portable handrail from ATDA to spacecraft hatch	Spacecraft exter-ior on handrail-spacecraft hatch	22:49	22:49	23:29	:40	
Camera Placement-Retrieval/Film Change	Retro adapter camera film change	Standing in space-craft hatch	23:29	23:29	23:53	:24	
GLV Strip Retriev-al	———	"	23:53	23:53	25:13	1:20	
Camera Placement-Retrieval/Film Change	Unstow work station camera	"	25:13	25:13	26:13	:60	Pilot secures work station camera to ELSS.
Movement	Translation on adapter handrail to adapter work station	Adapter handrail	26:13	26:13	28:38	2:25	Pilot pauses twice to position umbilical during aft translation Total interval of umbilical was 30 seconds
Positioning/Restraint	Evaluation of work station and initial body positioning	In foot restraints in adapter	28:38	28:38	28:48	:10	
Camera Placement-Retrieval/Film Change	Work station camera instal-lation	"	28:48	28:48	30:01	1:13	

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Rebalancing Break		*In adapter*	30:01	30:01	31:01	:60	*Pilot undertakes short unassisted neutral buoyancy checkout.*
Rest (4)	———	"	31:01	31:01	32:52	1:51	*Evaluation of resting with various restraint points.*
Adapter Work Station Preparation	———	"	32:52	32:52	34:35	1:43	
Positioning/Restraint	*Foot restraint evaluation*	*In foot restraints in adapter*	34:35	34:35	36:02	1:27	
Rest (5)	———	"	36:02	36:02	37:55	1:53	*Command pilot notes mission time as 44:15 at elapsed time of 36:20.*
Adapter Work Task (A)	*A1 - A2*	"	37:55	37:55	44:45	6:50	*Pilot switches work station camera to 6 FPS at beginning of these subtasks and returns camera to 1 FPS at end of subtasks. (simulated)*
Rest (6)	———	"	44:45	44:45	46:45	2:00	
Adapter Work Task (B)	*B1 - B5*	*In adapter*	46:45	46:45	62:48	16:03	*Subtasks B1 - B3 in foot restraints Subtasks B4, B5 on waist tethers only.*
Rebalance Break	———	———	62:48	62:48	69:53	7:05	
Rest (7)	———	*Waist tethers only in adapter*	69:53	69:53	71:53	2:00	
Adapter Work Task (C)	*C1 - C4*	"	71:53	71:53	77:08	5:15	*Velcro strip and connector evaluations*

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Positioning/Restraint	*Return to foot restraints*	*In foot restraints in adapter*	77:08	77:08	77:30	:22	
Rest (8)	————	"	77:30	77:30	79:30	2:00	
Adapter Work Station Cleanup	*Preparation to return to spacecraft hatch*	"	79:30	79:30	81:03	1:33	*Pilot secures handholds to ELSS*
Positioning/Restraint	*One foot restraint evaluation*	"	81:03	81:03	83:15	2:12	
Adapter Work Station Cleanup	————	"	83:15	83:15	85:32	2:17	*Camera and penlight retrieval*
Rest (9)	————	"	85:32	85:32	88:42	3:10	*Command pilot requests pilot to extend his rest period because they are ahead of schedule on their task/time line.*
Positioning/Restraint	————	"	88:42	88:42	89:42	:60	*Pilot makes several attempts to velcro portable handholds to ELSS. Low fidelity mockup prevents success.*
Movement	*Translation forward to spacecraft hatch area.*	*Adapter handrail*	89:42	89:42	90:46	1:04	
Camera Placement-Retrieval/Film Change	*Stowage of adapter work station camera and activation of retro adapter camera*	*Spacecraft hatch area*	90:46	90:46	92:19	1:33	
Rest (10)	————	"	92:19	92:19	93:04	:45	
Movement	*Translation forward to ATDA work station*	*Portable handrail and ATDA*	93:04	93:04	94:09	1:05	
ATDA Work Station Task (A)	*A1*	*ATDA work station*	94:09	94:09	96:19	2:10	*Initial portable handhold placement.*

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Rest (11)	———	ATDA work station	96:19	96:19	98:19	2:00	
ATDA Work Station Task (B)	B1 - B3	"	98:19	98:19	101:59	3:40	Pip pin/handhold connector and torque evaluation
Rest (12)	———	"	101:59	101:59	103:54	1:55	
ATDA Work Station Task (C)	C1 - C3	"	103:54	103:54	110:04	6:10	Torque and connector evaluation with single and both tethers
ATDA Work Station Cleanup	Jettison of pip pins, waist tethers and portable handholds	"	110:04	110:04	110:39	:35	
ATDA Work Station Task (D)	D1 - D2	"	110:39	110:39	113:39	3:00	Connector and torque re-evaluation using no tethers
Movement	Translation aft to spacecraft hatch area	Portable handrail and spacecraft	113:39	113:39	114:43	1:04	
Camera Placement-Retrieval/Film Change	Retrieval and stowage of retro adapter camera	Spacecraft hatch area	114:43	114:43	116:23	1:40	Torque wrench stowage
Ingress	———	Standing in spacecraft hatch	116:23	116:23	116:50	:27	
Handrail Jettison	———	"	116:50	116:50	117:18	:28	
Hatch Closure Preparation	Umbilical recovery, hatch holding device deployment and hatch seal checkout	"	117:18	117:18	117:47	:29	
Hatch Closure	Assuming seated position in cockpit	Seated in cockpit seat of spacecraft	117:47	117:47	———	———	Hatch not closed in simulation time line

TABLE XI. FLIGHT TIME LINE - FINAL ITERATION

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Positioning/Restraint Task	*Standup Familiarization*	*S/C hatch*	*0:00*	*42: 51:05*	*42: 52:44*	*1:40*	*Pilot evaluates free floating tendency while standing in s/c hatch. Pilot states that he cannot percieve any forces large enough to cause floating of large objects*
Communications	———	"	*1:40*	*42: 52:45*	*42: 52:54*	*:09*	*CP calls for a 2 minute rest period*
Rest (1)	———	"	*1:52*	*42: 52:57*	*42: 53:49*	*:52*	*Pilot commented that this rest did not appear necessary as no real activity had occurred*
Camera Placement-Retrieval/Film Change	*Selection of optimum camera placement mode*	*Standing in s/c hatch*	*3:01*	*42: 54:06*	*42: 55:45*	*1:39*	*Optimum (time) placement mode- utilized a combination of positioning aid from s/c with increased freedom of movement while outside s/c hatch*
Positioning/Restraint	*Preparation for camera placement evaluation outside hatch area*	*S/C hatch area*	*4:40*	*42: 55:45*	*42: 56:30*	*:45*	
Camera Placement-Retrieval/Film Change	*Selection of optimum placement mode*	"	*5:25*	*42: 56:30*	*42: 57:25*	*:55*	
Positioning/Restraint	*Preparation for rest period*	"	*6:20*	*42: 57:25*	*42: 57:52*	*:27*	*Pilot stated that he had to get proper position and "hold on to something" to get complete rest*
Rest (2)	———	*S/C exterior*	*6:54*	*42: 57:59*	*42: 59:42*	*1:43*	*Pilot rests while holding on to handrail*
Positioning/Restraint	*Umbilical extension prior to movement to docking bar*	"	*8:37*	*42: 59:42*	*43: 00:47*	*1:05*	
Movement	*Translation from s/c hatch to docking bar along portable handrail*	———	*9:47*	*43: 00:52*	*43: 01:33*	*:41*	*Pilot noted slight tendency to 'go head over heels', counteracted by light torque.*

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Positioning/Restraint	*Evaluation of tether dynamics*	*S/C exterior, tethered to hand-rail*	*10:35*	*43: 01:40*	*43: 08:25*	*1:45*	*Concomittant evaluation of ELSS cooling capacity. Evaluation similar to effects during standup EVA. Slight cooling of extremities.*
Agena Tether	———	*S/C exterior, tethered to ATDA rings*	*12:23*	*43: 03:28*	*43: 05:48*	*2:20*	*Slight disturbance to Agena during task due to speed of movement. Slight problem with hookup of docking bar clamp.*
Positioning/Restraint	*Preparation for rest*	*S/C - ATDA interface*	*14:59*	*43: 06:04*	*43: 06:52*	*:38*	*Command pilot states that performance so far is faster than target and calls for rest period.*
Rest (3)	———	"	*15:52*	*43: 06:57*	*43: 09:04*	*2:07*	*Pilot notes rough edged material on s/c sep. plane.*
S-10	———	"	*18:03*	*43: 09:08*	*43: 12:47*	*3:39*	*Some difficulty evidenced due to; requirements for fine hand operation, and to avoid touching experiment surface.*
Positioning/Restraint	*Repositioning on ATDA prior to work station setup*	*ATDA work station*	*21:48*	*43: 12:53*	*43: 13:33*	*:40*	*CP photographed pilot tether restrained position*
ATDA Work Station Preparation	*Initial evaluation - setup of ATDA work station*	"	*22:47*	*43: 13:52*	*43: 14:58*	*1:06*	*Pilot commented on possibility of kicking L band antenna*
Rest (4)	———	"	*23:58*	*43: 15:03*	*43: 20:11*	*5:08*	*43:16:05 - 43:17:45 (messages to Houston) 43:18:28 CC suggested slow down due to elevated heart rate*

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Positioning/Restraint	*Initial ATDA work station setup*	*ATDA work station*	*29:09*	*43: 20:14*	*43: 21:03*	*:49*	*Initial evaluation of velcro handholds and placement of handholds for later work station tasks. CP orders return to hatch at 41:21:03*
Communications	*Evaluation of ice formation on H_2 vent*	*S/C exterior*	*30:01*	*43: 21:06*	*43: 22:22*	*1:16*	*Pilot comments that docking clamp should not be used as handhold since it might come loose.*
Movement	*Return to s/c hatch*	*S/C exterior on portable handrail standing in hatch*	*31:19*	*43: 22:24*	*43: 23:08*	*:44*	*Pilot asks CP to check umbilical condition*
Camera Placement - Retrieval/Film Change	*Film change for 70mm Maurer.*	*S/C hatch*	*32:20*	*43: 23:25*	*43: 23:51*	*:26*	
GLV Strip Retrieval	———	"	*33:02*	*43: 24:07*	*43: 25:43*	*1:36*	*Stowage of 4 strips slight concern to pilot*
Camera Placement - Retrieval/Film Change	*Stowage of adapter work station camera on ELSS*	"	*34:42*	*43: 25:47*	*43: 26:59*	*1:12*	*Required pilot to connect auxiliary tether then velcro cameras to ELSS.*
Positioning/Restraint	*Umbilical feed out prior to movement to adapter*	*S/C exterior on portable handrail*	*36:05*	*43: 27:10*	*43: 27:36*	*:26*	
Movement	*Translation from portable handrail along retro-handrail to pigtail*	*Along retro-equipment adapter exterior*	*36:37*	*43: 27:42*	*43: 29:44*	*2:02*	*Includes routing umbilical through pigtail and initial entry into the foot restraints. CP comments that pilot is perturbing entire s/c due to motions*

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Camera Placement - Retrieval/ Film change	Initial setup and checkout of adapter work station camera	Foot restraints - facing adapter work station	38:40	43: 29:45	43: 32:07	2:22	Pilot observes that linkage on camera bracket is broken (push bar mechanism which operates ball detent)
Rest (5)	———	In foot restraints in adapter	41:02	43: 32:07	43: 33:04	:57	Pilot comments that his left heel seems to be riding a little high in the foot restraint
Positioning/Restraint	Foot restraint evaluation	In foot restraints in adapter	42:09	43: 33:14	43: 36:04	2:50	Pilot observes neutral suit position, movement in fore and aft direction return to neutral position. Pilot leans back parallel to longitudinal spacecraft axis (similar to exercise in water immersion simulation). Pilot comments that this maneuver is "a little bit harder" than the same maneuver in the water. (greater leg force).
Communications	———	In foot restraints in adapter	45:01	43: 36:06	43: 36:47	:41	Pilot and CP discuss adapter camera condition and umbilical condition
Work Station Preparation	Penlight deployment	In foot restraints in adapter	45:47	43: 36:52	43: 37:30	:38	Pilot observes that one penlight is "bulged" apparently from heat.
	Camera activation	In foot restraints in adapter	46:27	43: 37:33	43: 38:13	:40	Pilot observes that camera appears to be working
Rest (6)	———	"	47:17	43: 38:22	43: 40:31	2:09	
Work Station Preparation	Camera Activation	"	49:37	43: 40:42	43: 43:18	2:36	Attempt to activate work station camera not successful

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Adapter Work Task (A)	*Torque evaluation Connector operation*	*In foot restraints in adapter*	52:17	43: 43:22	43: 50:43	7:21	*Pilot notes that he had difficulty removing wrench from work station pouch.*
Rest (7).	——	"	59:38	43: 50:43	43: 52:18	1:35	
Adapter Work Task (B_1)	*Cutter evaluation*	"	61:17	43: 52:22	44: 03:15	10:53	*Pilot notes cutting wires is a one handed task; cutting fluid disconnect is relatively difficult- and is a two handed operation*
	Pip pin and portable handhold evaluation	"					*Pilot comments "medium ELSS flow with monitoring is adequate" for work tasks accomplished so far*
	Saturn bolt removal	"					
	Remove right waist tether from ELSS; attach to work station ring. Remove left tether from ELSS and attach to work station	"					
	Saturn bolt evaluation	*Waist tethers only in adapter*					*Pilot encounters difficulty with melted rubber retainer on Saturn bolt causing increased work load because of need to use both hands to remove bolt.*
Rest (8)	——		72:11	44: 03:16	44: 04:20	1:04	

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Adapter Work Task (B_2)	*Saturn bolt evaluation*	*Waist tethers only in adapter*	*73:25*	*44: 04:30*	*44: 10:54*	*6:24*	*Pilot notes that "Saturn bolt workspace is way too close to the tether".*
	Hook and ring evaluation	"					*Pilot comments that "small ring requires more delicate handling to get proper position in hand".*
Rest (9)	———	"	*79:53*	*44: 10:58*	*44: 12:29*	*1:31*	*CP and pilot consult their respective task check lists. Pilot notes 'feet are actually chilly".*
Adapter Work Task (C)	*Velcro strip evaluation*	"	*81:32*	*44: 12:37*	*44: 16:19*	*3:42*	*CP comments "running 4 minutes behind schedule" before this task begins.*
	Center connector evaluation	"					*Pilot notes that body position is not a problem for center connector.*
	Left hand connector evaluation	"					*Pilot notes that left hand connector task is "a bit more difficult" because of lack of handholds.*
	Right hand connector evaluation	"					*Pilot notes that right hand connector is "quite an easy one"*
Adapter Work Station Cleanup	*Retrieve work station camera*	*In foot restraints in adapter*	*85:36*	*44: 16:41*	*44: 18:55*	*2:14*	*Pilot reports difficulty detaching camera from bracket. Task completed after only slight delay.*
Movement	*Translation along retro/equipment adapter to s/c hatch*	*Adapter handrail*	*88:37*	*44: 19:42*	*44: 20:13*	*:31*	*Pilot notes that work station camera almost tangled in pigtail as he rounded the adapter separation plane.*

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Camera Placement-Retrieval/Film Change	Exchange cameras. Pilot hands in work station camera CP gives pilot retro-adapter camera	Spacecraft exterior hatch area	89:21	44:20:26	44:23:00	2:34	Pilot installs retro-adapter camera and makes exposure settings 1/250 at 6 frames per second
Movement	Translation from s/c hatch to ATDA work station	Spacecraft exterior Portable handrail to spacecraft/ATDA interface	91:57	44:23:02	44:24:16	1:14	
ATDA Work Station Task (a)	Pip pin and portable hand-hold evaluation. (Initial placement)	ATDA work station	93:21	44:24:26	44:26:39	2:13	Pilot requests a rest period after initially placing pip pins and handholds.
Rest (10)	———	"	95:54	44:26:59	44:30:06	3:07	
ATDA Work Station Task (b)	Pip pin and portable hand-hold evaluation. (Dynamic evaluation) Fluid and electrical disconnect evaluation Apollo torque wrench evaluation	"	99:10	44:30:15	44:34:01	3:46	Pilot comments "pip pins that swivel are not adequate as handholds"
Rest (11)	———	"	102:27	44:34:02	44:35:56	1:54	Pilot comments "Looks like a panel on the back of the Agena is a little loose". Closer examination during rest period revealed electrical umbilical panel that failed to "slam shut on left-off"

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
ATDA Work Station Task (c)	Apollo torque wrench evaluation	ATDA work station	104:51	44:35:56	44:42:21	6:25	Pilot notes that "the only things that are coming close to being warm are my arms". He attributes this to the "close fit of the suit in the arms".
	Torque re-evaluation using only one waist tether	"					Pilot notes his contact points to be "right arm, right waist tether, and right foot".
	Torque re-evaluation using no tethers						
Observation and Final Work Station Cleanup	Jettison of pip pins, waist tethers and portable hand holds TDA work task using no tethers (electrical connector evaluation)	"	111:16	44:42:21	44:43:02	:41	Pilot makes one last check of left hand thrusters
Movement	Translation to s/c hatch along portable handrail	Spacecraft exterior/portable handrail	111:57	44:43:02	44:43:53	:51	
Optical Surface Evaluation	Attempt to clean s/c window with wiper cloth	Spacecraft exterior Portable handrail and CP window	112:55	44:44:00	44:44:55	:55	Pilot notes that "Agena tether looks hooked up and the docking bar clamp is engaged"
Communications	———	Spacecraft exterior on portable handrail	113:54	44:44:59	44:45:41	:42	
Umbilical Stowage	Positioning	Spacecraft exterior on portable handrail, hatch area	114:36	44:45:41	44:46:24	:43	

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Ingress	*Equipment Stowage*	*Standing in space craft hatch*	*115:19*	*44: 46:24*	*44: 47:48*	*1:24*	
Thruster Checkout Task	*Visual observations*	*Standing in space-craft hatch*	*116:56*	*44: 48:01*	*44: 49:50*	*1:49*	*Pilot notes that on comparison the thruster in question does not appear to work efficiently*
Handrail Jettison	—	"	*118:56*	*44: 50:01*	*44: 50:45*	*:44*	
Hatch Closure Preparation	*Clearing of hoses and equipment. Checking hatch seal area. Deploy hatch holding device.*	"	*119:40*	*44: 50:45*	*44: 51:50*	*1:05*	*Pilot comments that hatch seal is clear except for some "flecks of dust".*
Hatch Closure	*Hatch locks in locked position*	*Seated in cockpit seat of spacecraft*	*121:01*	*44: 52:06*	—	—	*Final hatch lock activated at 2 minutes before sunset.*

TABLE XII - AIRCRAFT SIMULATION TIME LINE - FINAL ITERATION ENVIRONMENTAL RESEARCH ASSOCIATES

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Movement	*Translate up handrail to docking cone*	*Handrail*	0	0	8.1	8.1	*Aircraft simulation does not use a spacecraft mockup for this subtask ; only the TDA and handrail.*
Restraint	*Attach left waist tether to TDA ring*	*Handrail*		8.1	20.8	12.7	
"	*Attach right waist tether to TDA ring*	"		20.8	34.6	13.7	*No tether was attached to the handrail ring.*
———	———	———		34.6	37.1	2.5	*Blackout : Time between zero gravity parobolas on film.*
Restraint	*Evaluating position with tethers while attached to TDA*	*TDA*		37.1	55.5	18.3	*Camera is faded out as subject appears to lose his zero gravity mode.*
———	———	———		55.5	56.1	.6	*Blackout*
Positioning	*Adjusting position on tethers*	*TDA*		56.1	59.7	3.7	
Agena Tether	*Attach tether to docking bar*	*TDA*		59.7	75.0	15.2	*Time measured to point when tether is pulled tight on docking bar*
———	———	———		75.0	76.2	1.2	*Blackout*
Positioning	*Maneuver to favorable position to activate docking bar clamp*	*TDA*		76.2	82.6	6.5	
Agena Tether	*Docking bar clamp activation*	*TDA*		82.6	95.8	13.2	
———	———	———		95.8	101.9	6.0	*Blackout*

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
S - 10	Farring removal and jettison	TDA		101.9	115.4	13.5	Appears to be time missing at the beginning of this task
S - 10	S - 10 removal from slots	"		115.4	119.9	4.5	
—	—	—		119.9	129.0	9.1	Blackout
S - 10	S - 10 placement on velcro			129.0	149.0	20.0	
—	—	—		149.0	150.8	1.8	Blackout
Restraint	Detach right waist tether from TDA	TDA		150.8	156.0	5.2	Pilot re-attaches this tether to his ELSS
"	Detach left waist tether from TDA	"		156.0	170.4	14.3	Pilot re-attaches this tether to his ELSS
Movement	Translation back handrail from TDA towards space-craft hatch	"		170.4	186.4	15.9	Pilot moves back to end of handrail. During this translation he turns 180° at approximately half way down handrail.
Camera Task	Install Work station camera	Adapter work station		238.5	250.8	12.3	This task is not complete on film
Torque Task	Torquing operation on fixed bolt	"		250.8	293.2	42.4	Film ends before this task is complete

TABLE XIII

TIME COMPARISON OF CAMERA RETRIEVAL AND PLACEMENT TASKS

TASK	ORBITAL*	WATER * SIMULATION
MOVEMENT FROM TDA TO SPACECRAFT HATCH	40	44
RETRO CAMERA RETRIEVAL & INSTALLATION	24	26
GLV STRIP RETRIEVAL	80	96
WORK STATION CAMERA RETRIEVAL	60	72

* TIME - SECONDS

TABLE XIV. FLIGHT TIME LINE-WORK STATION TASKS - DETAILED ANALYSIS

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Adapter Work Task (A)	*Torque*	*In foot restraints*	*52:17*	*43: 43:22*	*43: 49:02*	*5:40*	*Pilot notes difficulty removing wrench from pouch.*
	Electrical connector (center)	*"*	*57:57*	*43: 49:02*	*43: 50:43*	*1:41*	*Pilot notes that "crease in glove on thumb" is beginning his hand trouble.*
Adapter Work Task (B_1)	*Cutter*	*"*	*61:17*	*43: 52:22*	*43: 55:51*	*3:29*	*Pilot comments that "medium ELSS flow with monitoring is adequate" for work tasks accomplished so far.*
	Pip pin and portable hand-hold	*"*	*64:46*	*43: 55:51*	*43: 57:55*	*2:04*	
	Saturn bolt	*"*	*66:50*	*43: 57:55*	*43: 59:44*	*1:49*	
	Attach waist tethers to work station, remove feet from restraints and evaluate body dynamics	*Waist tethers only*	*68:39*	*43: 59:44*	*44: 01:25*	*1:41*	
	Saturn bolt	*"*	*70:20*	*44: 01:25*	*44: 03:15*	*1:50*	*Pilot encounters difficulty with melted rubber retainer on Saturn bolt causing increased work load because of need to use both hands to remove bolt.*
Adapter Work Task (B_2)	*Saturn bolt*	*"*	*73:25*	*44: 04:30*	*44: 07:31*	*3:01*	*Pilot notes that "Saturn bolt workspace is way too close to the tethers".*
	Hook and ring	*"*	*76:26*	*44: 07:31*	*44: 10:54*	*3:23*	*Pilot comments that "small ring requires more delicate handling to get proper position in hand."*

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Adapter Work Task (C)	Velcro strip evaluation	Waist tethers only in adapter	81:32	44: 12:37	44: 13:13	:36	CP comments "running 4 minutes behind schedule" before this subtask begins.
	Center connector evaluation	"	82:08	44: 13:13	44: 13:52	:39	Pilot notes that body position is not a problem for center connector.
	Left hand connector evaluation	"	82:57	44: 14:02	44: 14:37	:35	Pilot notes that left hand connector is "a bit more difficult" because of lack of handholds.
	Right hand connector evaluation	"	83:32	44: 14:37	44: 16:19	1:42	Pilot notes that right hand connector is "quite an easy one".
TDA Work Task (a)	Pip pin and portable hand-hold evaluation (initial placement)	TDA work station using waist tethers	93:21	44: 24:26	44: 26:39	2:13	Pilot requests a rest period after initially placing pip pins and handholds.
TDA Work Task (b)	Pip pin and portable hand-hold evaluation (dynamics evaluation)	"	99:10	44: 30:15	44: 31:13	:58	Pilot comments "pip pins that swivel are not adequate as handholds."
	Fluid and electrical disconnect evaluation	"	100:08	44: 31:13	44: 33:25	2:12	
	Apollo torque wrench evaluation	"	102:20	44: 33:25	44: 34:01	:36	
TDA Work Task (c)	Apollo torque wrench evaluation	"	104:51	44: 35:56	44: 38:23	2:27	Pilot notes that "the only things that are coming close to being warm are my arms" He attributes this to the "close fit of the suit in the arms".

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
TDA Work Task (C) (Continued)	Torque re-evaluation using only right waist tether	TDA work station using right waist tether only	107:18	44: 38:23	44: 40:20	1:57	Pilot notes his contact points to be "right arm , right waist tether and right foot".
	Torque re-evaluation using no tethers	TDA work station no restraints	109:15	44: 40:20	44: 42:21	2:01	

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Adapter Work Task (A)	Torque evaluation	In foot restraints in adapter	37:55	37:55	38:55	:60	Pilot removes torque wrench from pouch and adjusts torque dial for loosening operation on fixed bolt.
	Torque task-loosening evaluation	"	38:55	38:55	40:20	1:25	
	Torque task-tightening evaluation	"	40:20	40:20	41:20	:60	
	Torque task-1/2 inch bolt evaluation	"	41:20	41:20	42:40	1:20	
	Center connector evaluation	"	42:40	42:40	43:50	1:10	
Adapter Work Task (E)	Cutter evaluation	"	46:45	46:45	50:10	3:25	
	Pip pin and portable hand-hold evaluation	"	50:10	50:10	50:58	:48	
	Saturn bolt removal	"	50:58	50:58	52:41	1:43	Pilot hooks up left and right waist tethers.
	Saturn bolt removal	Waist tethers only in adapter	52:41	52:41	59:28	6:47	Pilot removes both feet from restraints at beginning of this subtask. Pilot comments that "he broke rubber retainer strip around bolt" during removal task.
	Hook and ring evaluation	"	59:28	59:28	62:48	3:20	Pilot sets camera at 6 FPS for this task.

Task	Subtask	Position	Elapsed Time	Start	Finish	Interval	Comments
Adapter Work Task (C)	Nylon and steel velcro strip evaluation	Waist tether only in adapter	71:53	71:53	72:23	:30	Pilot adjusts his tethers and and changes camera setting at end of this subtask
	Center connector evaluation	"	72:58	72:58	73:18	:20	
	Left hand connector evaluation	"	73:18	73:18	76:18	3:00	Pilot changes camera back to 1 FPS at 73:03
	Right hand connector evaluation	"	76:18	76:18	77:08	:50	
TDA Work Task (a)	Pip pin and portable hand-hold evaluation (initial placement)	Two waist tethers	94:09	94:09	96:19	2:10	
TDA Work Task (b)	Pip pin and portable hand-hold evaluation	"	98:19	98:19	99:25	1:06	
	Fluid and electrical disconnector evaluation	"	99:25	99:25	100:24	:59	
	Apollo torque wrench evaluation	"	100:24	100:24	101:59	1:35	
	Apollo torque evaluation	One waist tether only	103:54	103:54	104:17	:23	
	Electrical and fluid connector evaluation	"	104:17	104:17	107:54	3:37	
	Torque re-evaluation	"	107:54	107:54	110:04	2:10	
TDA Work Task (c)	Connector evaluation	No tether	110:39	110:39	111:54	1:15	
	Torque re-evaluation	"	111:54	111:54	113:39	1:45	

TABLE XVI

ELECTRICAL CONNECTOR TASK COMPARISON

CONNECTOR DESCRIPTION	ORBITAL *	WATER * SIMULATION
PORT	35	180
CENTER	39	20
STARBOARD	102	50

* TIME - SECONDS

TABLE XVII
BIOMEDICAL INSTRUMENTATION COMPONENTS FOR THE WATER SIMULATION

SENSOR	PRIMARY	BACKUP
O_2 Content (exhaust)	Beckman type E2	Beckman type D1
CO_2 Content (exhaust)	Perkin Elmer Type AS	Liston-Becker (nd)
Airflow	Fisher-Porter 'Florater' (nd)	o
EKG	Skin Mounted Electrodes (sternal)	o
Respiratory Rate	Impedance Pneumograph	o
Skin Temperature	Thermistor Probe (posterior to earlobe)	o

TABLE XVIII

RESULTS OF BIOMEDICAL ANALYSIS OF GEMINI XII PREFLIGHT SIMULATION

ASTRONAUT ALDRIN

CODE	TASK	BTU/Hr. Ft.^{2}	HEART RATE	RESP. RATE	BODY TEMP.	CO_2
A	Resting In Water	63.7	65	12	97.1	.47
B	Agena Tether Task	38.2	85	15	97.0	.57
C	Adapter Work Task	53.1	90	24	97.8	.62
D	Torque Wrench Evaluation	40.6	95	18	96.6	.50
E	Velcro Evaluation	57.2	75	18	97.6	.70
F	Apollo Torque Wrench Evaluation	37.3	80	12	97.8	.50
G	Working On Line	39.0	65	21	97.9	.45
H	Working On Line	69.3	100	27	98.2	.75

TABLE XIX

RESULTS OF BIOMEDICAL ANALYSIS OF GEMINI XII PREFLIGHT SIMULATION

CODE	TASK	BTU/Hr. $Ft.^2$	HEART RATE	RESP. RATE	BODY TEMP.	CO_2
A	Resting	37.5	65	6	97.9	-
B	Working - No Suit	54.3	70	12	97.4	-
C	Resting - No Pressure	19.2	65	9	97.6	-
D	Working - No Pressure	68.2	100	18	97.7	-
E	Resting - Pressurized	19.0	65	15	97.8	-
F	Working - Pressurized	82.1	150	27	98.2	.9
G	Resting - Pressurized	21.1	100	15	98.4	.4
-	Resting - 5% CO_2	12.6	130	27	99.4	.6
-	Working - 5% CO_2	165.0	135	28	99.9	off scale

TABLE XX TASK TIME - TASK ENERGY COMPARISON Page 1 of 3 ENVIRONMENTAL RESEARCH ASSOCIATES

TASK	ELAPSED TIME (min.:sec.)		TASK TIME (min.)			TASK ENERGY COST (BTU)		
	Flight	Preflight Simulation	Flight	Preflight Simulation	Increment	Flight	Preflight Simulation	Increment
Positioning/Restraint	0:00	0:00	1:40	:50	+ 0.84	12	5	+ 7
Rest (1)	1:52	4:35	:52	:25	+ 0.45	10	5	+ 5
Camera Placement-Retrieval/Film Change	3:01	:50	1:39	:60	+ 0.65	31	11	+ 20
Positioning/Restraint	4:40	2:55	:45	:25	+ 0.33	11	9	+ 2
Camera Placement-Retrieval/Film Change	5:25	3:20	:55	:65	- 0.06	12	17	- 5
Positioning/Restraint	6:20	4:25	:27	:10	+ 0.28	3	2	+ 1
Rest (2)	6:54	5:50	1:43	:30	+ 1.22	11	2	+ 9
Positioning/Restraint	8:37	6:20	1:05	:10	+ 0.91	13	1	+ 12
Movement	9:47	6:30	:41	:31	+ 0.16	12	1	+ 11
Positioning/Restraint	10:35	7:01	1:45	1:56	- 0.18	24	5	+ 19
Agena Tether	12:23	8:57	2:20	1:40	+ 0.66	37	17	+ 20
Positioning/Restraint	14:59	10:37	:38	1:30	- 0.87	5	23	- 18
Rest (3)	15:52	18:09	2:07	1:40	+ 0.45	19	9	+ 10
S-10	18:03	12:32	3:39	:55	+ 2.73	72	10	+ 62
Positioning/Restraint	21:48	13:27	:40	1:15	- 0.58	14	13	+ 1
TDA Work Station Preparation	22:47	14:42	1:06	3:27	- 2.35	28	56	- 28
Rest (4)	23:58	31:01	5:08	1:51	+ 3.28	198	26	+ 172
Positioning/Restraint	29:09	19:49	:49	3:00	- 2.12	20	6	+ 14
Movement	31:19	22:49	:44	:40	+ 0.06	14	4	+ 10
Camera Placement-Retrieval/Film Change	32:20	23:29	:26	:24	+ 0.03	9	3	+ 6
GLV Strips	33:02	23:53	1:36	1:20	+ 0.27	33	15	+ 18

TASK	ELAPSED TIME (min.:sec.)		TASK TIME (min.)			TASK ENERGY COST (BTU)		
	Flight	Preflight Simulation	Flight	Preflight Simulation	Increment	Flight	Preflight Simulation	Increment
Camera Placement-Retrieval/Film Change	34:42	25:13	1:12	:60	+ 0.20	24	17	+ 7
Positioning/Restraint	36:05	—	:26	—	+ 0.43	8	—	+ 8
Movement	36:37	26:13	2:02	2:25	- 0.38	42	41	+ 1
Camera Placement-Retrieval/Film Change	38:40	28:48	2:22	1:13	+ 1.15	73	7	+ 66
Rest (5)	41:02	36:02	:57	1:53	- 0.93	24	25	- 1
Positioning/Restraint	42:09	28:38	2:50	:10	+ 2.66	54	1	+ 53
Work Station Preparation	45:47	32:52	1:18	1:43	- 0.42	18	25	- 7
Rest (6)	47:17	44:45	2:09	2:00	+ 0.15	28	21	+ 7
Work Station Preparation	49:37	—	2:36	—	+ 2.60	36	—	+ 36
Adapter Work Task (A)	52:17	37:55	7:21	6:50	+ 0.52	146	110	+ 36
Rest (7)	59:38	69:53	1:35	2:00	- 0.42	18	33	- 15
Adapter Work Task (B_1)	61:17	46:45	10:53	6:56	+ 3.57	187	79	+ 108
Rest (8)	72:11	77:30	1:04	2:00	- 0.93	19	45	- 26
Adapter Work Task (B_2)	73:25	52:41	6:24	10:07	- 3.43	146	126	+ 20
Rest (9)	79:53	85:32	1:31	3:10	- 1.65	21	21	0
Adapter Work Task (C)	81:32	71:53	3:42	5:15	- 1.33	71	140	- 69
Adapter Work Station Cleanup	85:36	79:30	2:14	3:50	- 1.60	59	58	+ 1
Movement	88:37	89:42	:31	1:04	- 0.55	12	20	- 8

TASK	ELAPSED TIME (min.:sec.)		TASK TIME (min.)			TASK ENERGY COST (BTU)		
	Flight	Preflight Simulation	Flight	Preflight Simulation	Increment	Flight	Preflight Simulation	Increment
Camera Placement-Retrieval/Film Change	89:21	90:46	2:34	1:33	+ 1.01	63	39	+ 24
Movement	91:59	93:04	1:14	1:05	+ 0.15	32	24	+ 8
TDA Work Station Task (a)	93:21	94:09	2:13	2:10	+ 0.05	58	33	+ 25
Rest (10)	95:54	92:19	3:07	:45	+ 2.37	58	12	+ 46
TDA Work Station Task (b)	99:10	98:19	3:16	3:40	- 0.40	65	38	+ 27
Rest (11)	102:57	96:19	1:54	2:00	- 0.10	30	20	+ 10
TDA Work Station Task (c)	104:51	103:54	6:25	9:10	- 2.45	159	66	+ 93
Observation and Final Work Station Cleanup	111:16	110:04	:41	:35	+ 0.10	18	10	+ 8
Movement	111:57	113:39	:51	1:04	- 0.22	20	11	+ 9
Optical Surface Evaluation	112:55	4:55	:55	:55	0	30	7	+ 23
Umbilical Stowage	114:36	—	:43	—	+ 0.72	21	—	+ 21
Ingress	115:19	116:23	1:28	:27	+ 0.95	37	6	+ 31
Thruster Checkout	116:56	—	1:49	—	+ 1.82	31	—	+ 31
Handrail Jettison	118:56	116:50	:44	:28	+ 0.26	8	6	+ 2
Hatch Closure Preparation	119:40	117:18	1:05	:29	+ 0.60	17	6	+ 11
Hatch Closure	121:01	117:47	—	—	—	—	—	—

TABLE XXI

GT XII Task Complement

EVA EVALUATION TASKS

- RESTRAINT EVALUATION
- SUIT MOBILITY EVALUATION
- TORQUE
- MAINTENANCE

EVA SUPPORT TASKS

- CAMERA PLACEMENT & RETRIEVAL
- MOVEMENT
- REST

EXPERIMENT SUPPORT TASKS

- S-10
- AGENA TETHER
- GLV STRIPS

TABLE XXII

EVALUATION OBJECTIVES FOR VARIOUS EVA SUBTASKS

	Restraint Evaluation	Suit Mobility Evaluation	Torque	Maintenance
Camera Placement Evaluation				X
Rest (2)	X			
Foot Restraints	X	X		
Torque	X		X	X
Connector	X			X
Cutter	X			X
Pip-pins & Handhold	X			X
Saturn Bolt	X		X	X
Hook & Ring	X			X
Apollo Torque Wrench	X		X	X
Velcro Strips	X			X
Optical Surface Evaluation				X

TABLE XXIII

EFFECT OF RESTRAINT MODES ON WORK TASKS FOR FLIGHT AND WATER SIMULATION

	ADAPTER WORK TASKS							
	FOOT RESTRAINTS				WAIST TETHERS			
	FLIGHT		SIMULATION		FLIGHT		SIMULATION	
	Min : sec.	BTU/hr.	Min : sec.	BTU/hr.	Min : sec.	BTU/hr.	Min : sec.	BTU/hr.
TORQUE	7:29	1177.5	6:23	1096.6	4:51	1339.8	6:47	782.3
CONNECTOR	1:41	1042.9	1:10	810.3	2:56	1240.0	4:10	1664.8
CUTTER	3:29	1025.9	3:25	600.0	-	-	-	-
HOOK & RING	-	-	-	-	3:23	1201.0	3:20	621.6
VELCRO STRIP	-	-	-	-	:36	1000.0	:30	1200.0

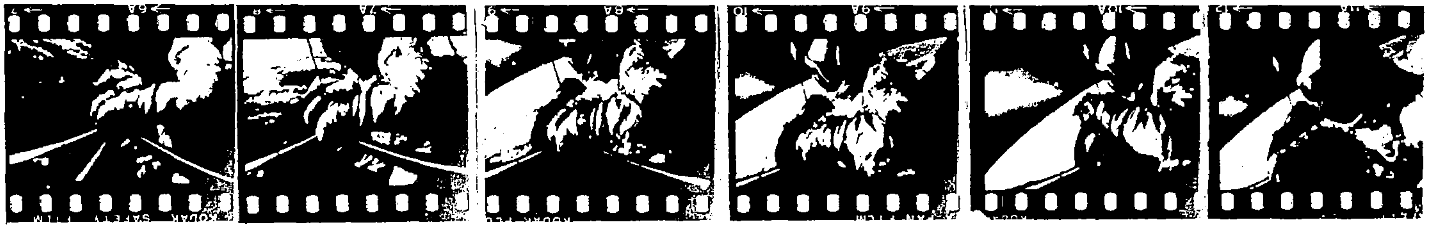
	TDA WORK TASKS											
	2 WAIST TETHERS				1 WAIST TETHER				0 WAIST TETHERS			
	FLIGHT		SIMULATION		FLIGHT		SIMULATION		FLIGHT		SIMULATION	
	Min:sec	BTU/hr	Min:sec.	BTU/hr	Min:sec.	BTU/hr	Min:sec.	BTU/hr	Min:sec	BTU/hr	Min:sec	BTU/hr
CONNECTOR	2:12	1153.6	:59	722.5	-	-	3:37	371.3	-	-	1:15	432.0
TORQUE	3:03	1158.9	1:35	410.1	1:57	1600.0	2:33	555.3	2:01	1835.8	1:45	356.6

TABLE XXIV
REST PERIOD PERFORMANCE

	FLIGHT		SIMULATION	
REST PERIOD	DURATION MIN.	WORKRATE BTU/hr.	DURATION MIN.	WORKRATE BTU/hr.
1	0.87	689.7	0.42	714.3
2	1.72	383.7	0.50	240.0
3	2.12	537.7	1.67	323.4
4	5.13	2318.8	1.85	843.2
5	0.95	1515.8	1.88	797.9
6	2.15	781.4	2.00	630.0
7	1.58	683.5	2.00	990.0
8	1.07	1065.4	2.00	1350.0
9	1.52	828.9	3.17	397.5
10	3.12	1115.4	0.75	960.0
11	1.90	947.4	2.00	600.0
12	-	-	1.92	625.0
TOTAL	22.13	-	20.16	-
AVERAGE	2.01	987.7	1.68	705.9

Handrail Erection

Figure 5-1 GEMINI XII COMPARISON OF ORBITAL FLIGHT, WATER & AIRCRAFT SIMULATION SELECTED FILM SEQUENCES (FIVE SECOND INTERVALS) Page 1 of 22



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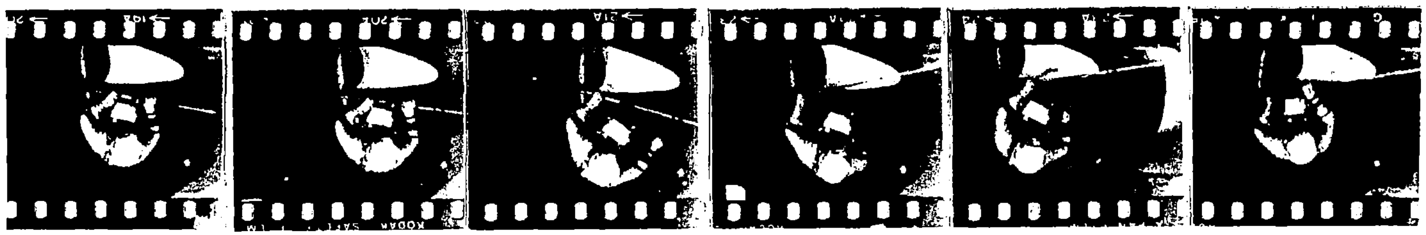
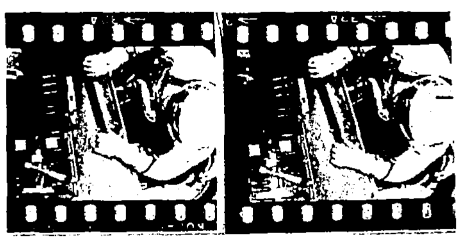


WATER



Handrail Erection

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Figure 5-1 Page 2 of 22

Movement From Hatch To TDA

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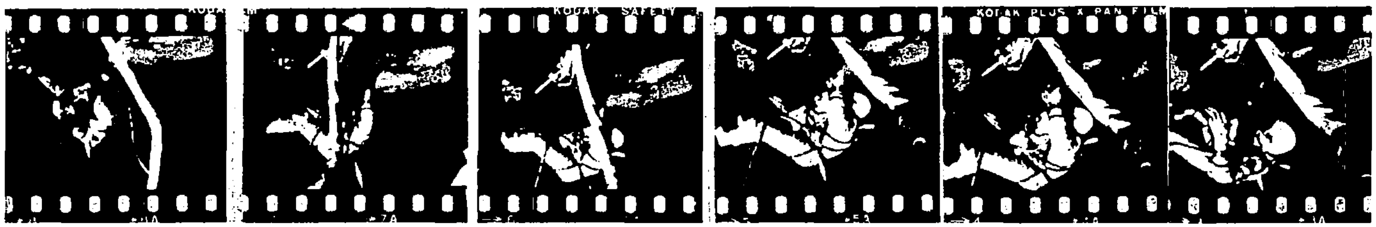

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Figure 5-1 Cont'd. **Page 3 of 22**

Movement From Hatch To TDA

Waist Tether Evaluation

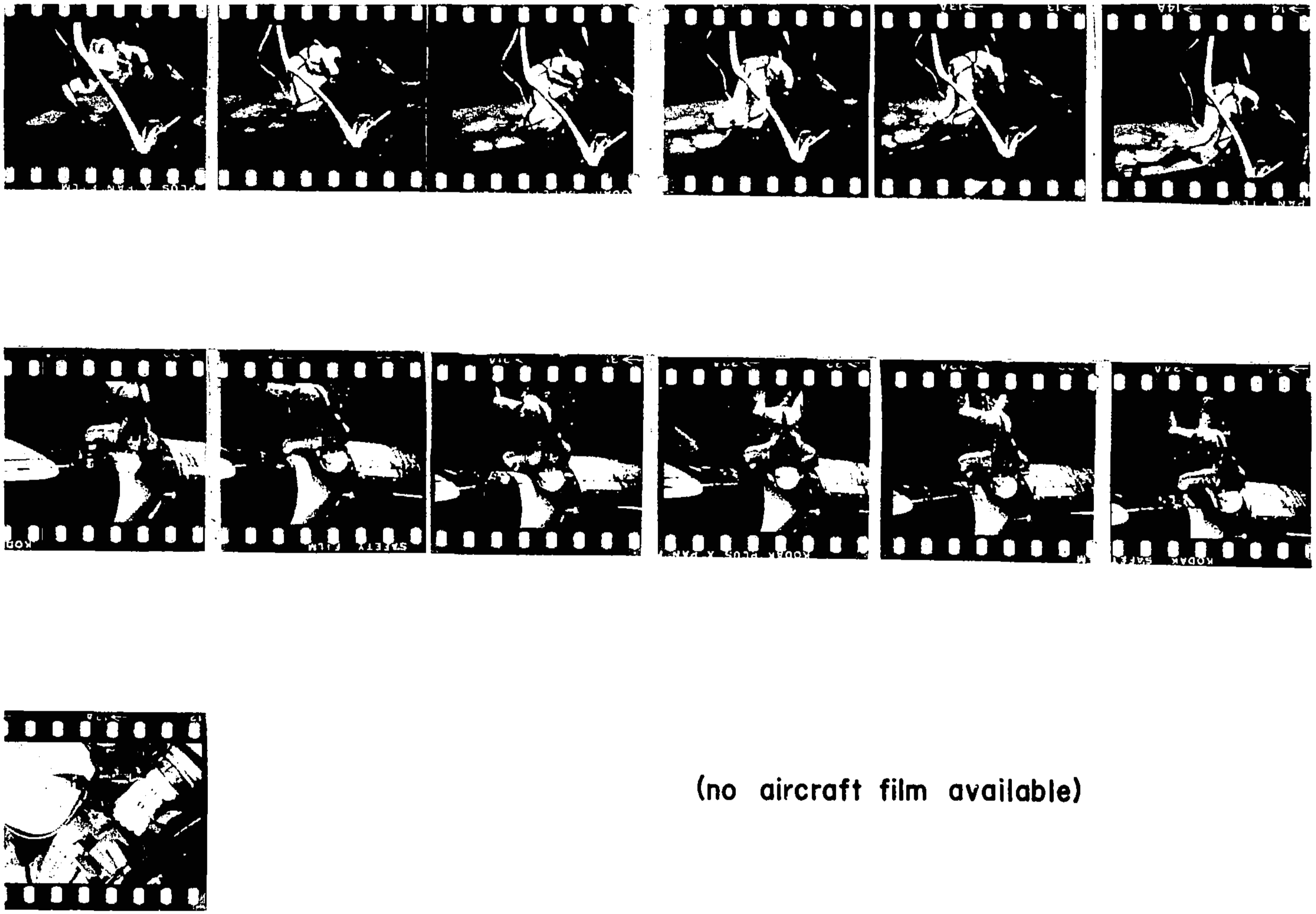

Figure 5-1 Cont'd. Page 4 of 22

Waist Tether Evaluation Rest

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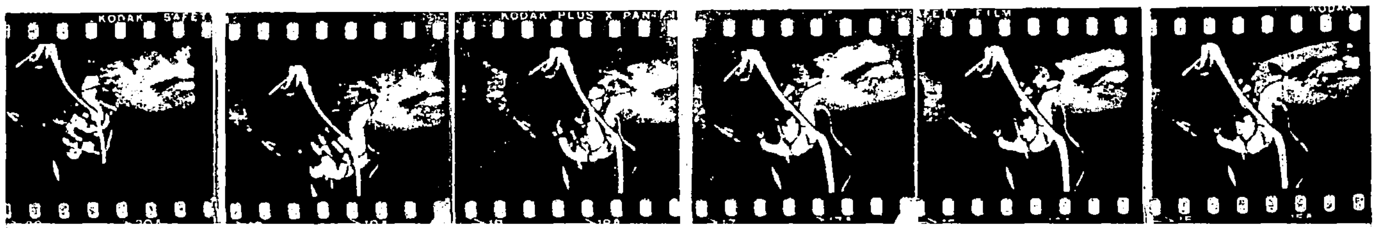

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Figure 5-1 Cont'd. Page 5 of 22

Rest

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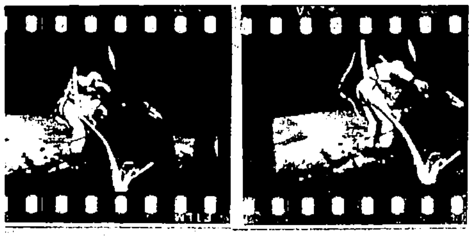

WATER

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Figure 5-I Cont'd. Page 6 of 22

Agena Tether Task

Figure 5-1 Cont'd.. Page 7 of 22

Agena Tether Task

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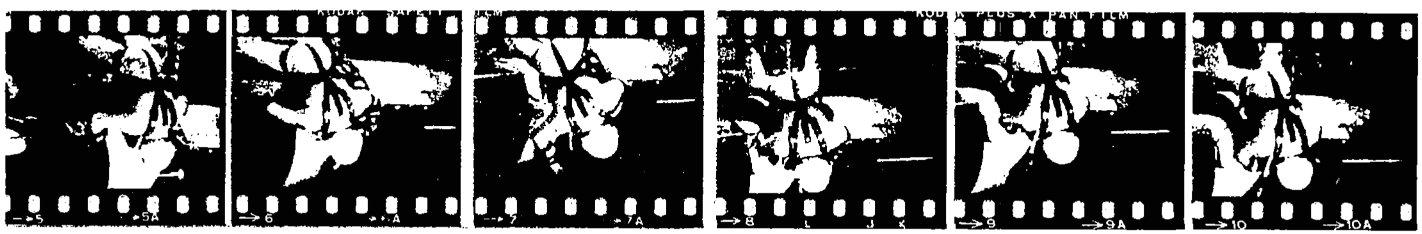

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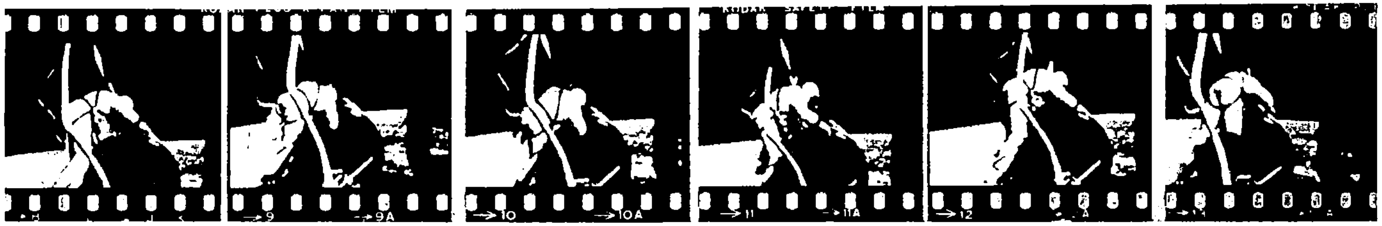
Figure 5-1 Cont'd. Page 8 of 22

Agena Tether Task



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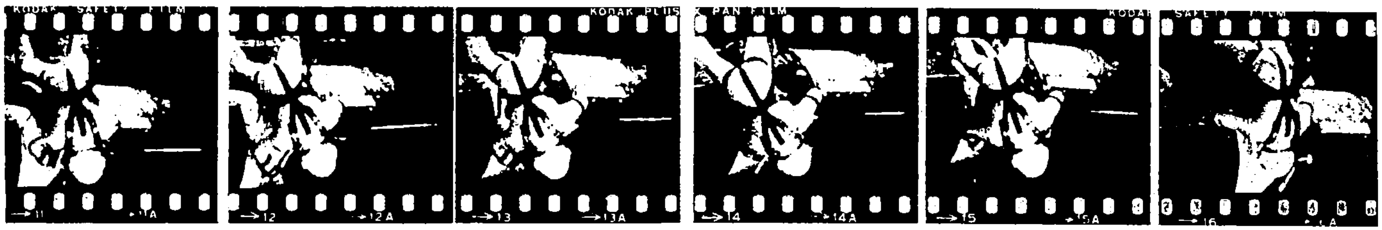

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Figure 5-1 Cont'd. Page 9 of 22

Agena Tether Task

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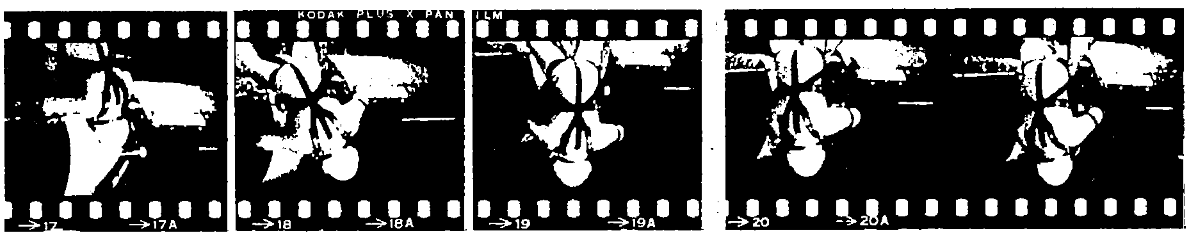

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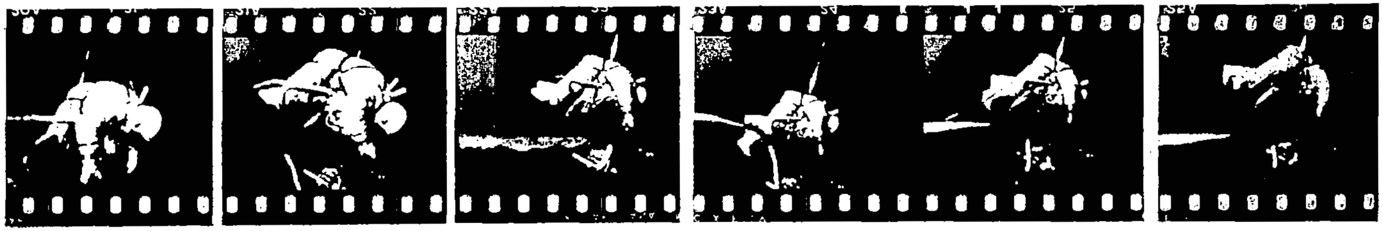
Figure 5-1 Cont'd. Page 10 of 22

Movement From Hatch To TDA Work Station



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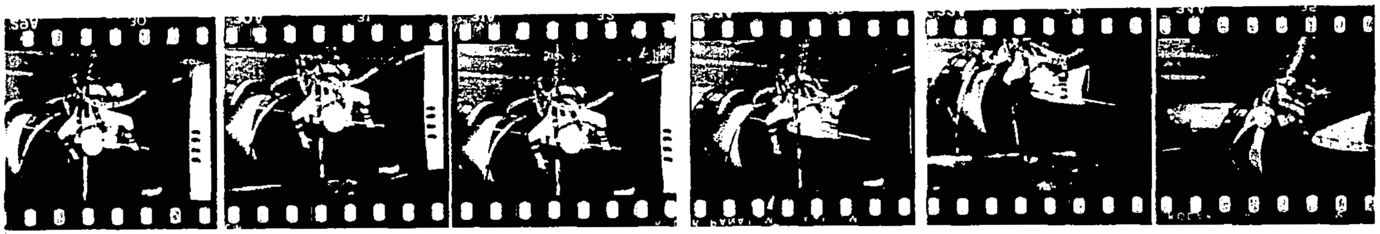

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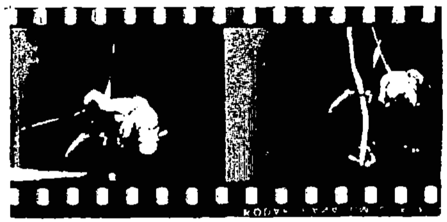
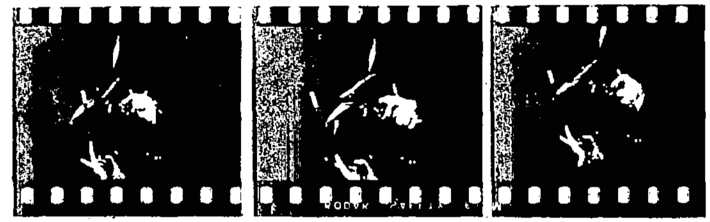
Figure 5-1 Cont'd. Page 11 of 22

Movement (Cont'd.)

TDA Work Tasks: Pip-Pin & Handhold Placement





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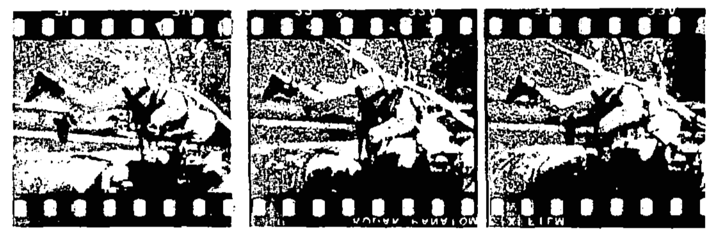

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Figure 5-1 Cont'd. Page 12 of 22

Pip-Pin & Handhold Placement

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Figure 5-1 Cont'd. **Page 13 of 22**

Pip-Pin & Handhold Placement

Figure 5-1 Cont'd. Page 14 of 22

Pip-Pin & Handhold Placement

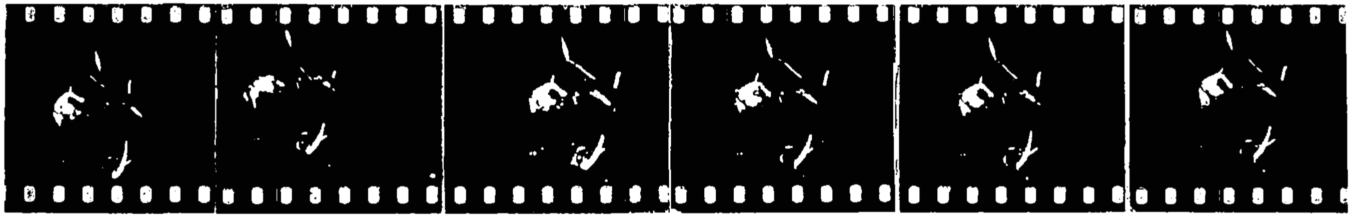

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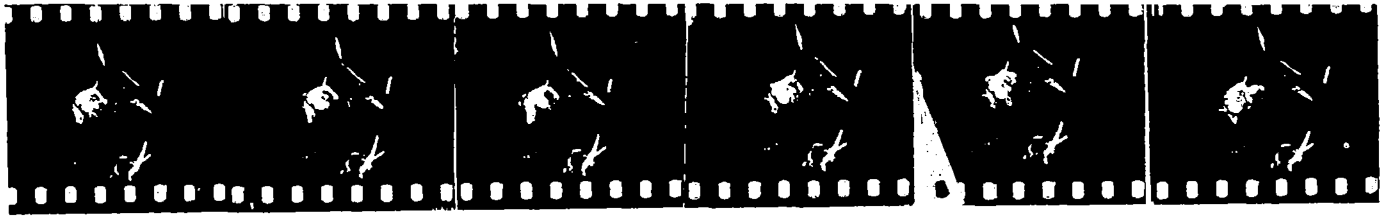
Figure 5-1 Cont'd. **Page 15 of 22**

Pip-Pin & Handhold Placement



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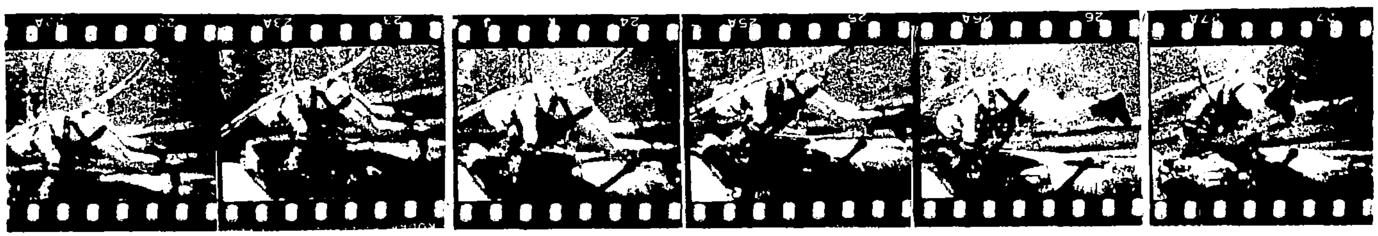

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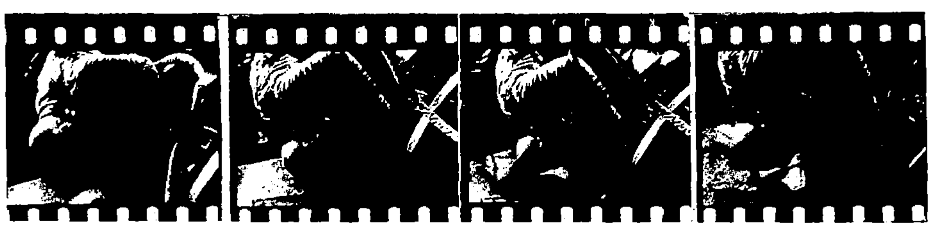

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Figure 5-1 Cont'd.   Page 16 of 22

Pip-Pin & Handhold Placement

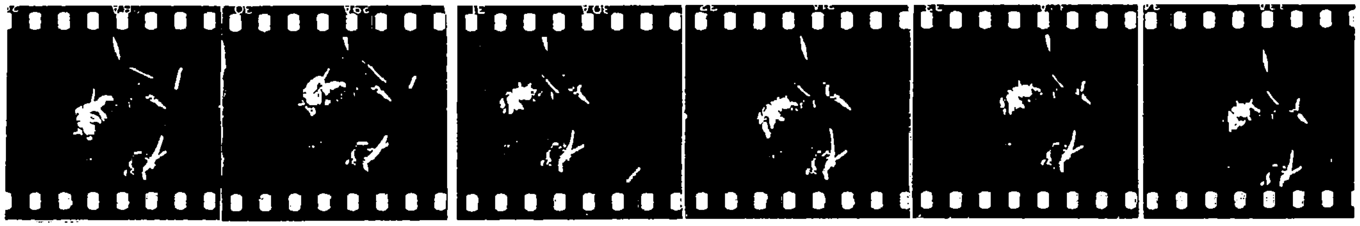

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Figure 5-1 Cont'd. Page 17 of 22

Pip-Pin & Handhold Placement

Rest On TDA

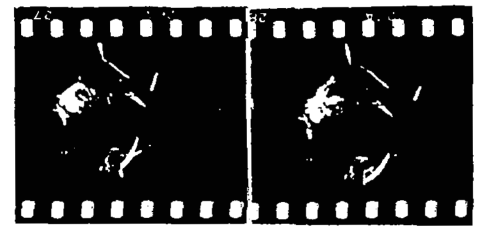

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Figure 5-1 Cont'd. Page 18 of 22

Rest On TDA

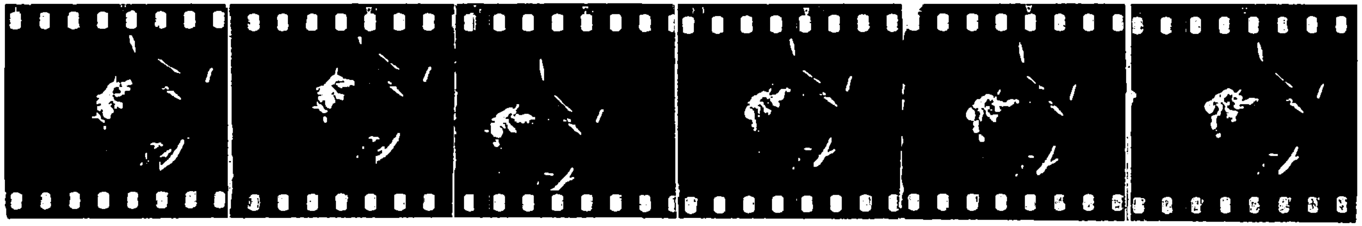

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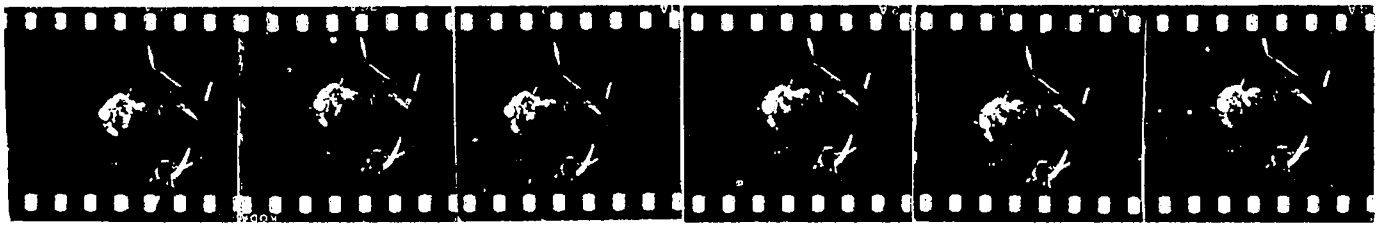
Figure 5-1 Cont'd. Page 19 of 22

Rest On TDA



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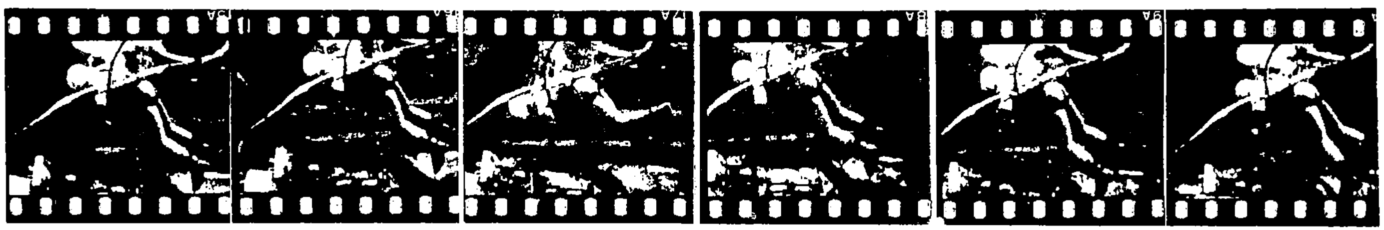

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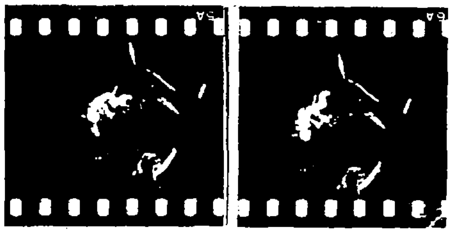
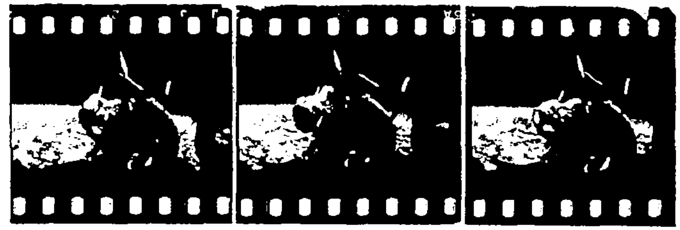
Figure 5-1 Cont'd. Page 20 of 22

Rest On TDA

Waist Tether Adjustment





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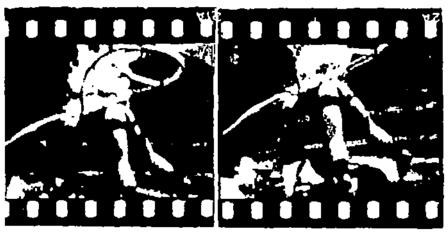

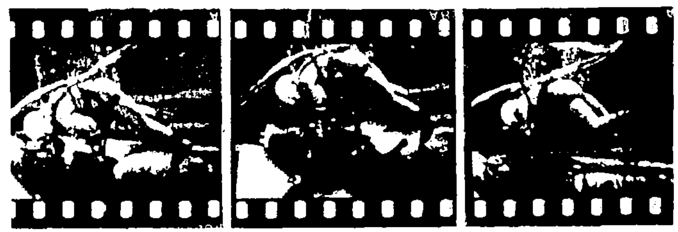

WATER

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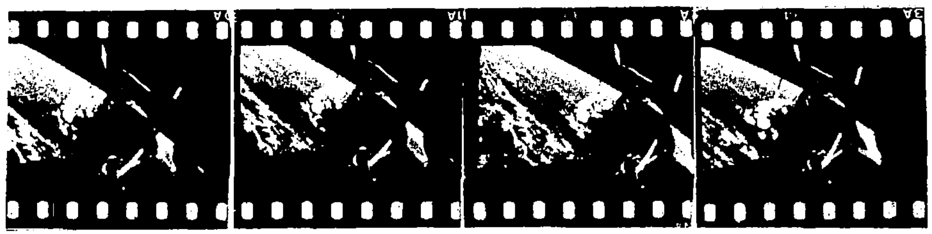
AIRCRAFT

Figure 5-1 Cont'd. Page 21 of 22

Apollo Torque Wrench Evaluation



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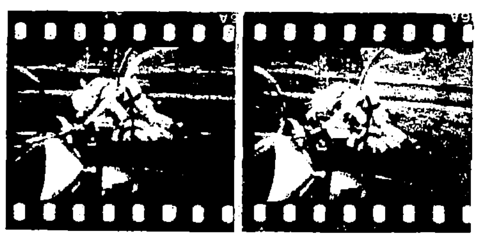

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AIRCRAFT

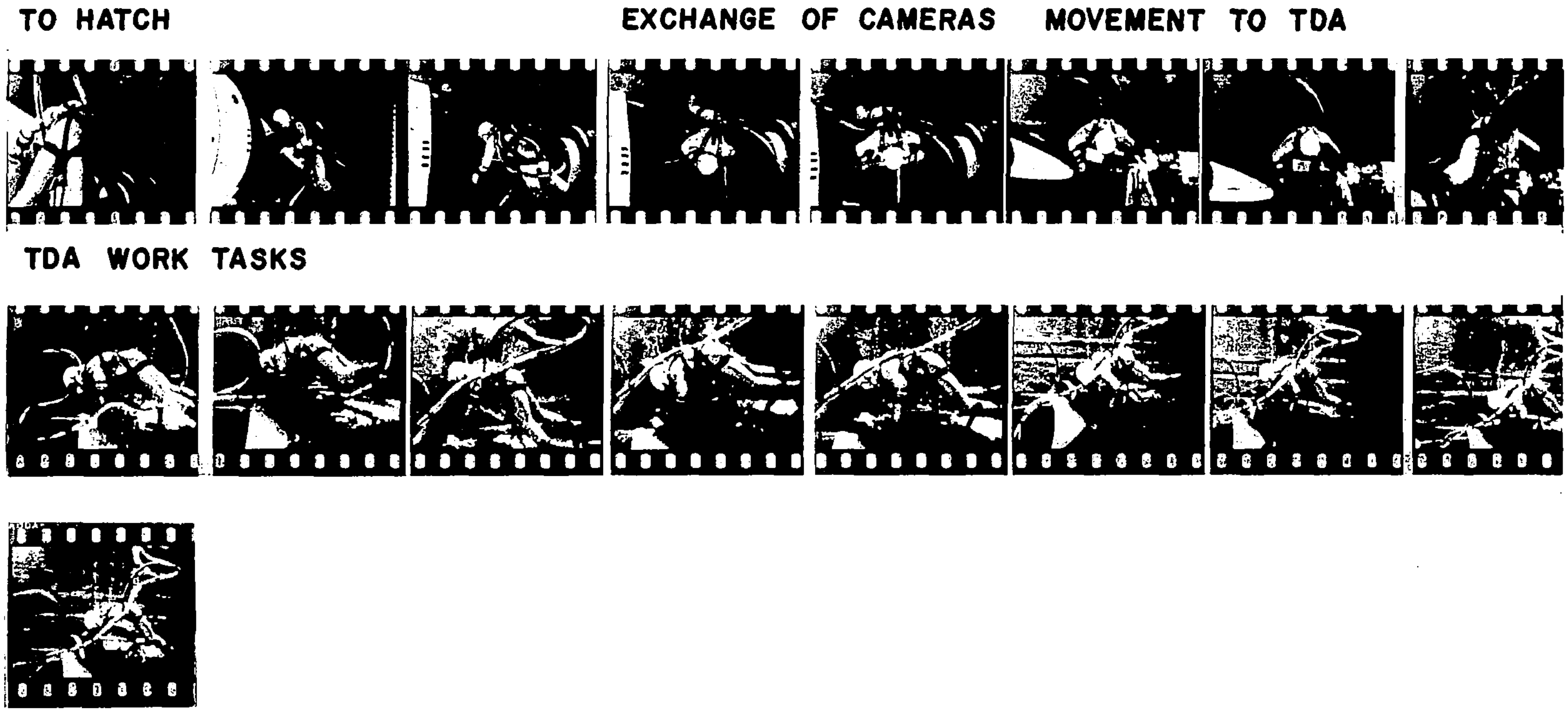
Figure 5-1 Cont'd. Page 22 of 22

Figure 5-2 Gemini XII SEQUENCE OF PREFLIGHT WATER SIMULATION (30 SECOND INTERVALS)

Figure 5-2 Cont'd.

Figure 5-2 Cont'd.

Figure 5-2 Cont'd.



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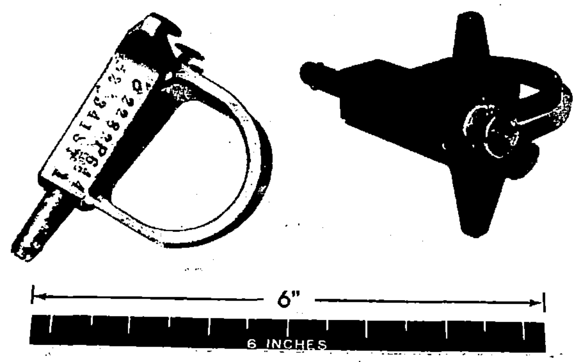


Figure 5-3 PIP PIN DEVICE

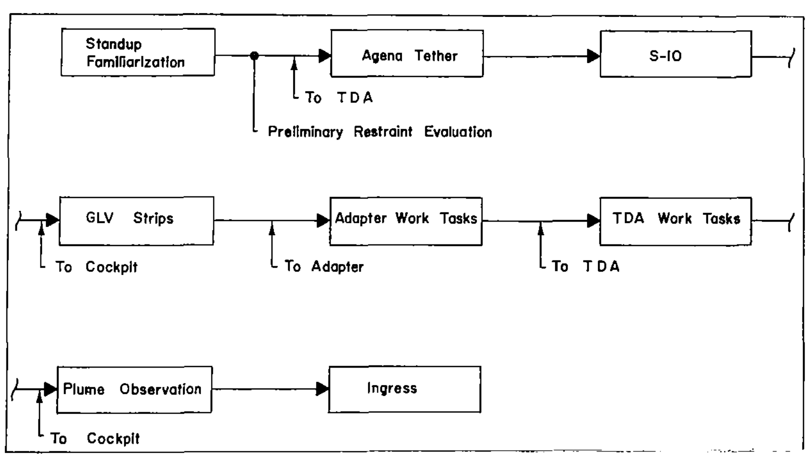
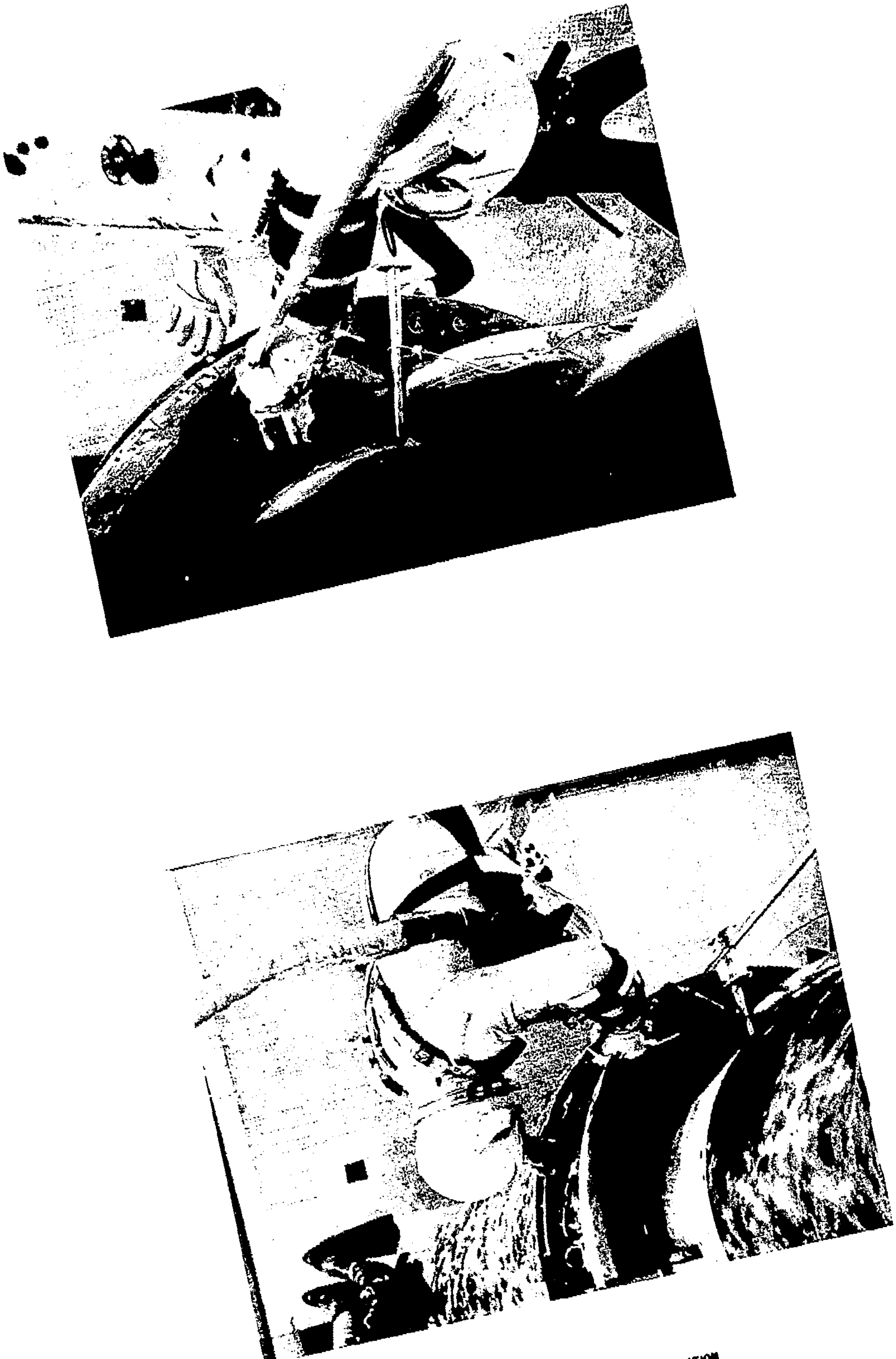


Figure 5-4 MAJOR TASK-EVENTS OF THE GEMINI XII UMBILICAL EVA



8-6 DOCKING BAR CONFIGURATION

(*) connotes time line not continuous

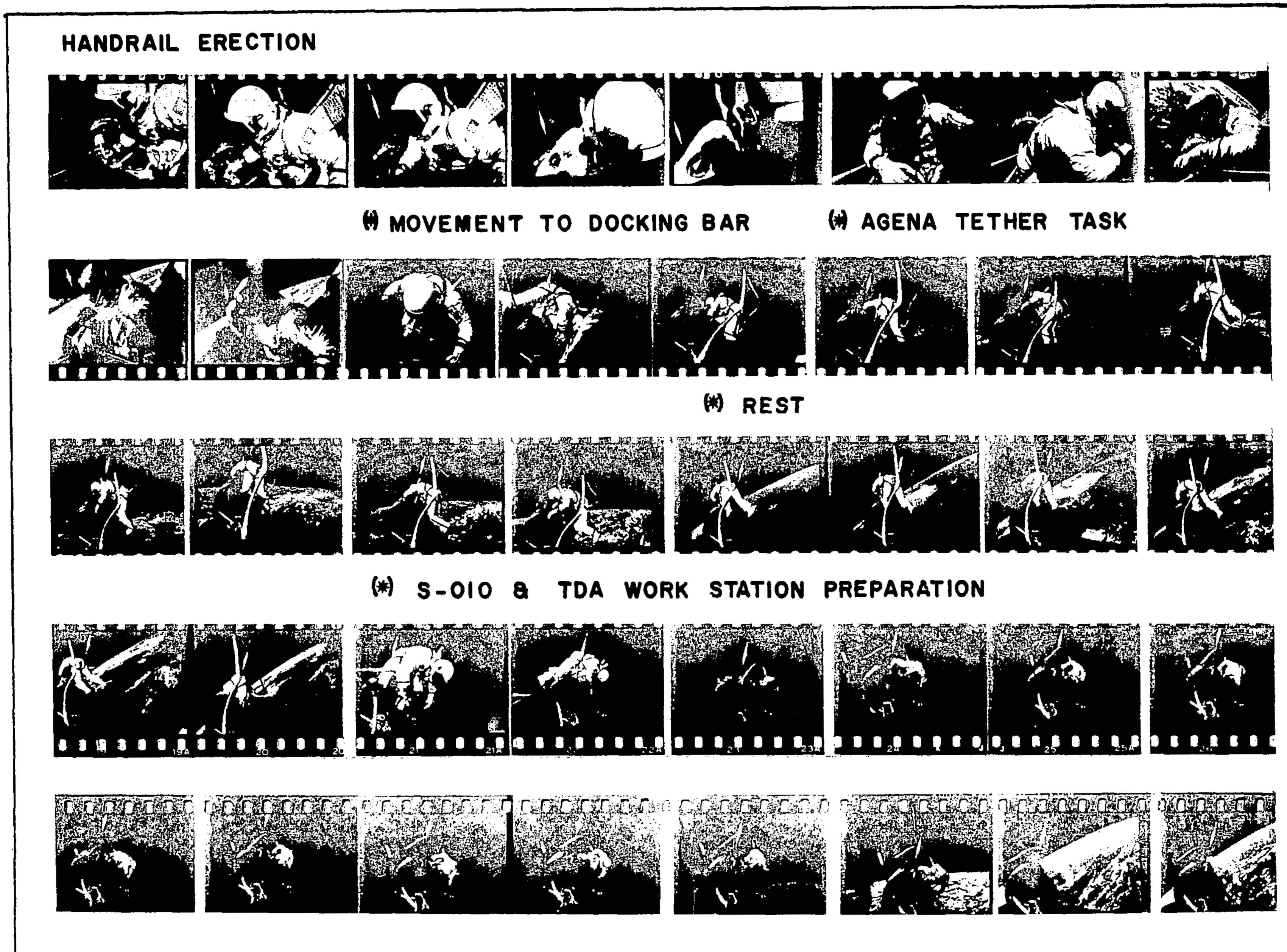


Figure 5-6 SEQUENCE OF AVAILABLE FILM FROM THE GEMINI XII FLIGHT (THIRTY SECOND INTERVALS)

(*) connotes time line not continuous

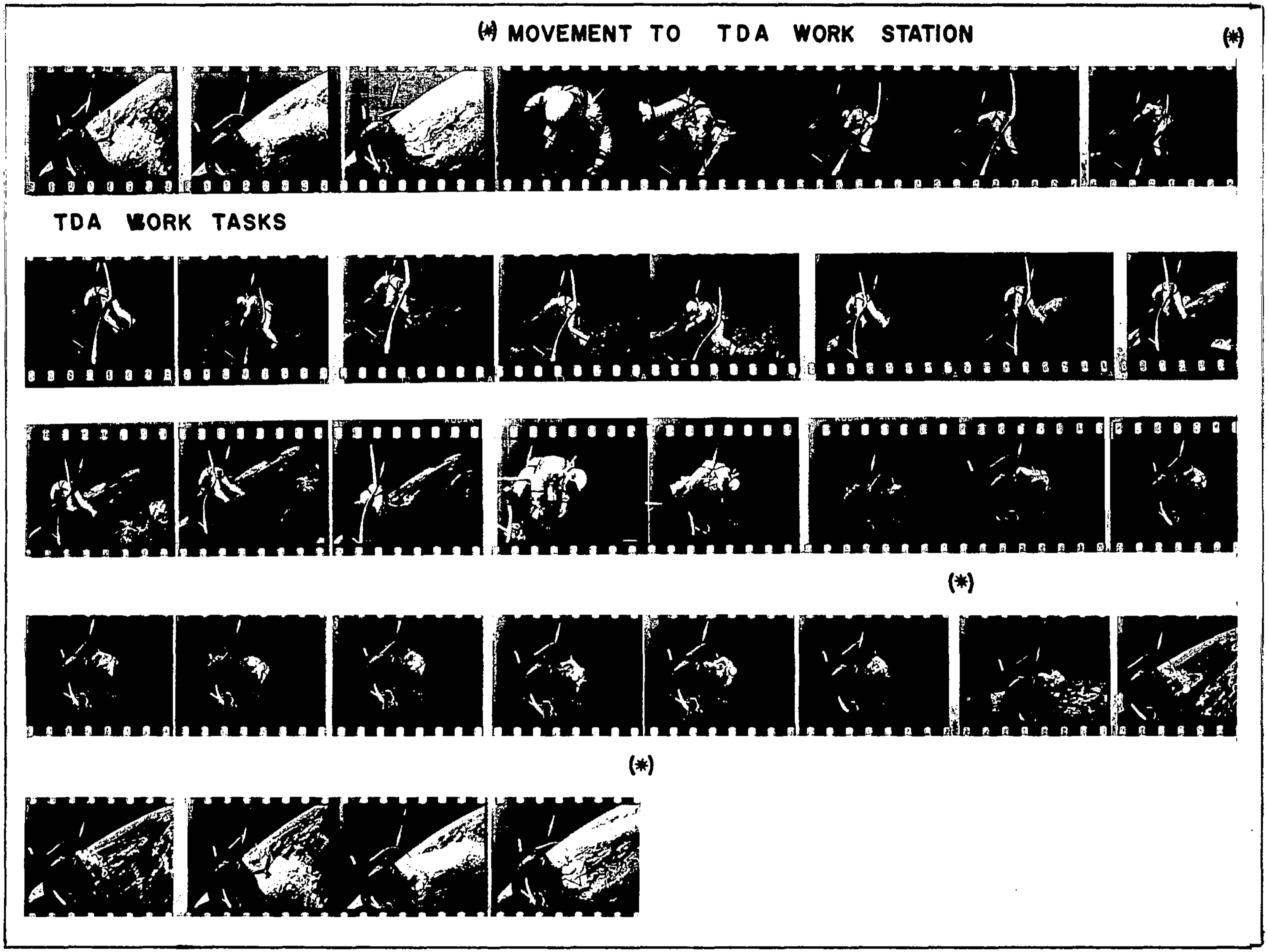


Figure 5-6 Cont'd.

(*) connotes time line not continuous

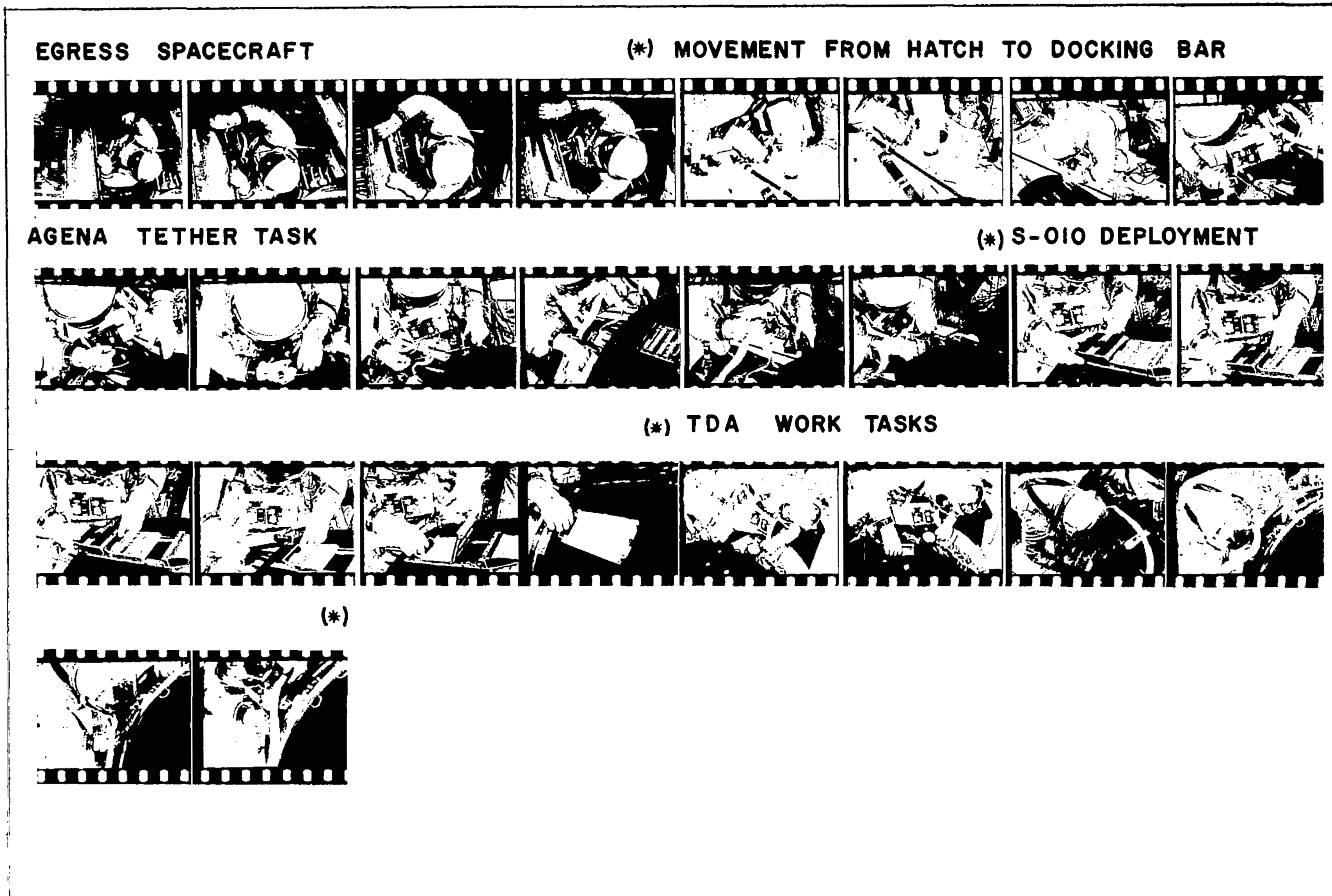


Figure 5-7 SEQUENCE OF AVAILABLE AIRCRAFT SIMULATION FILM
(THIRTY SECOND INTERVALS)

NASA-S-66-11799

Figure 5-8 LEG TETHER CONFIGURATION

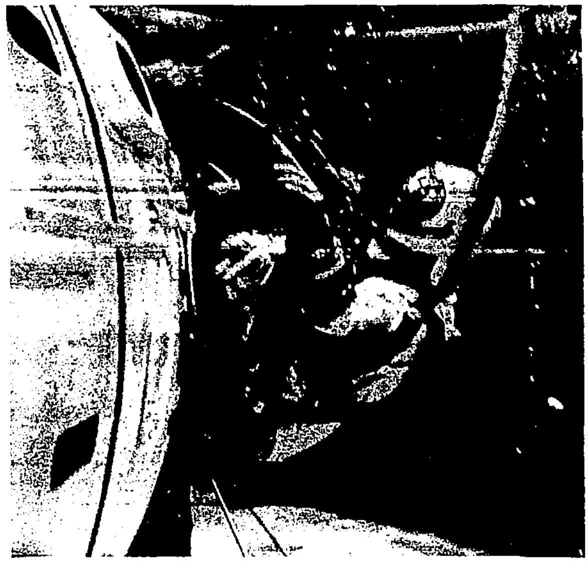


Figure 5-9 CAMERA PLACEMENT EVALUATION WHILE STANDING IN COCKPIT UNTETHERED

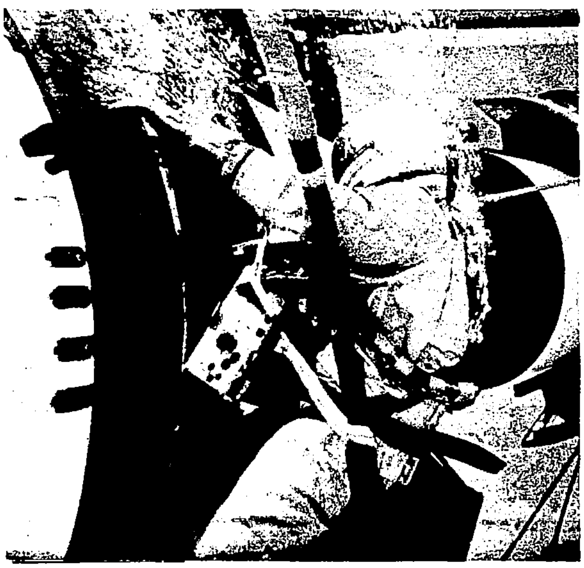


Figure 5-10 CAMERA PLACEMENT EVALUATION - BODY OUTSIDE SPACECRAFT HATCH

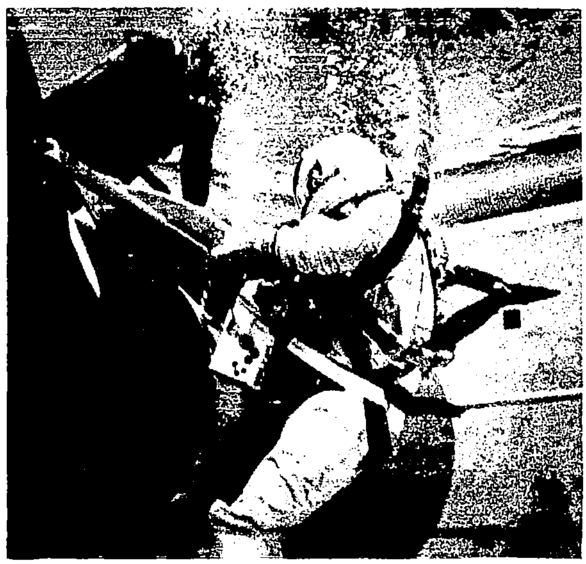


Figure 5-11 PILOT'S INITIAL RESTING POSITION ON PORTABLE HANDRAIL

Figure 5-12 RIGHT WAIST TETHER TO PORTABLE HANDRAIL RING

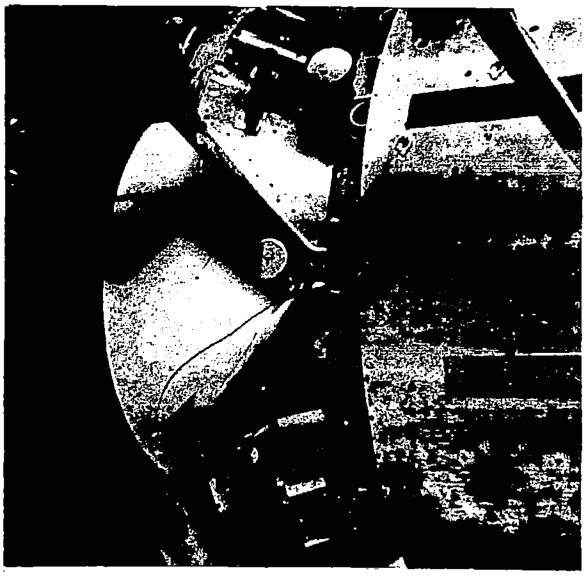


Figure 5-13 DOCKING CONE U-BOLT ATTACHMENT POINT FOR WAIST TETHER

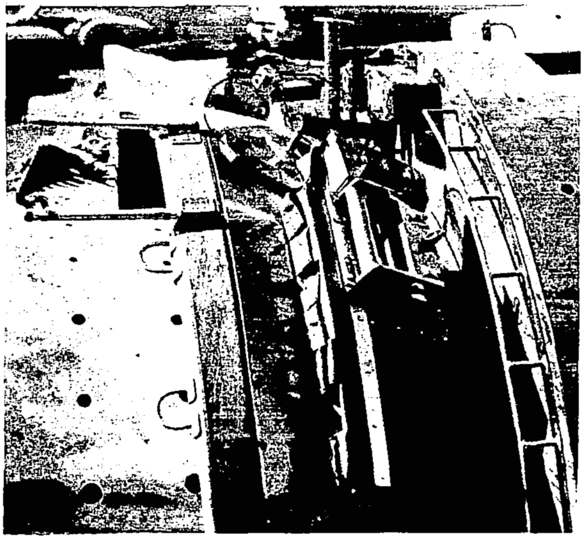


Figure 5-14 AGENA TETHER CONFIGURATION PRIOR TO ACTIVATION BY ASTRONAUT

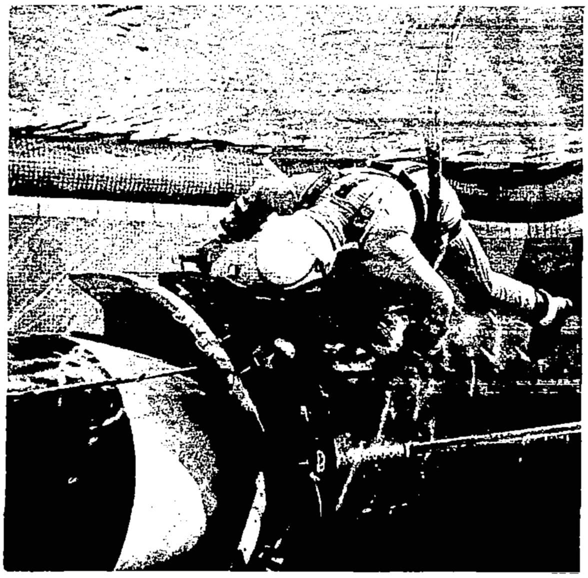


Figure 5-15 AGENA TETHER DEPLOYED

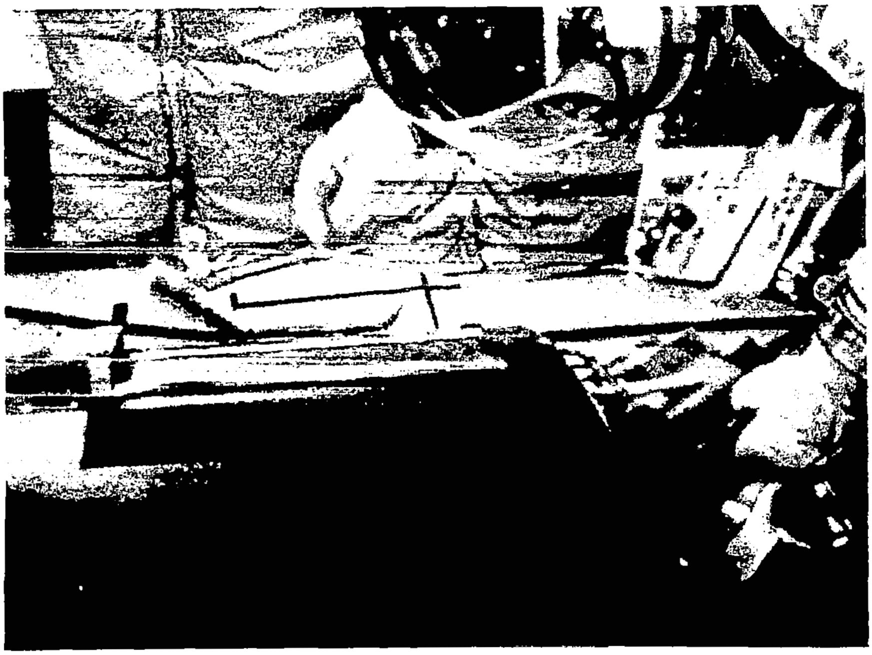


Figure 5-16 S-010 FULLY DEPLOYED ON TDA

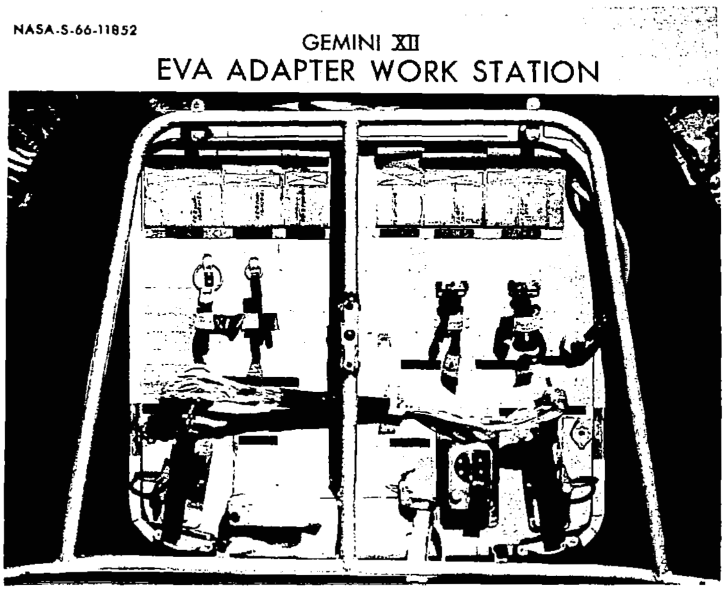


Figure 5-17 ADAPTER WORK STATION TASK BOARD

Figure 5-18 ASTRONAUT ALDRIN PERFORMING CENTER ELECTRICAL CONNECTOR EVALUATION

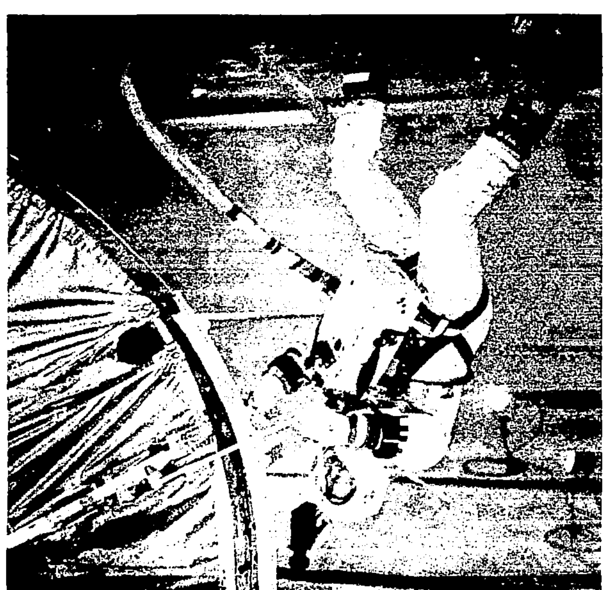


Figure 5-19 ASTRONAUT ALDRIN DURING MOVEMENT FROM ADAPTER TO SPACECRAFT HATCH AREA

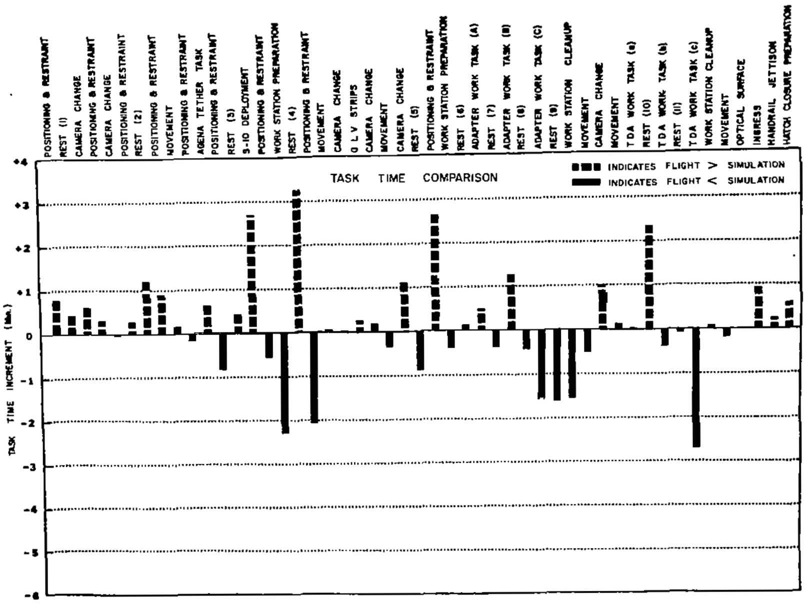


Figure 6-20 FLIGHT & WATER SIMULATION TASK TIME COMPARISON

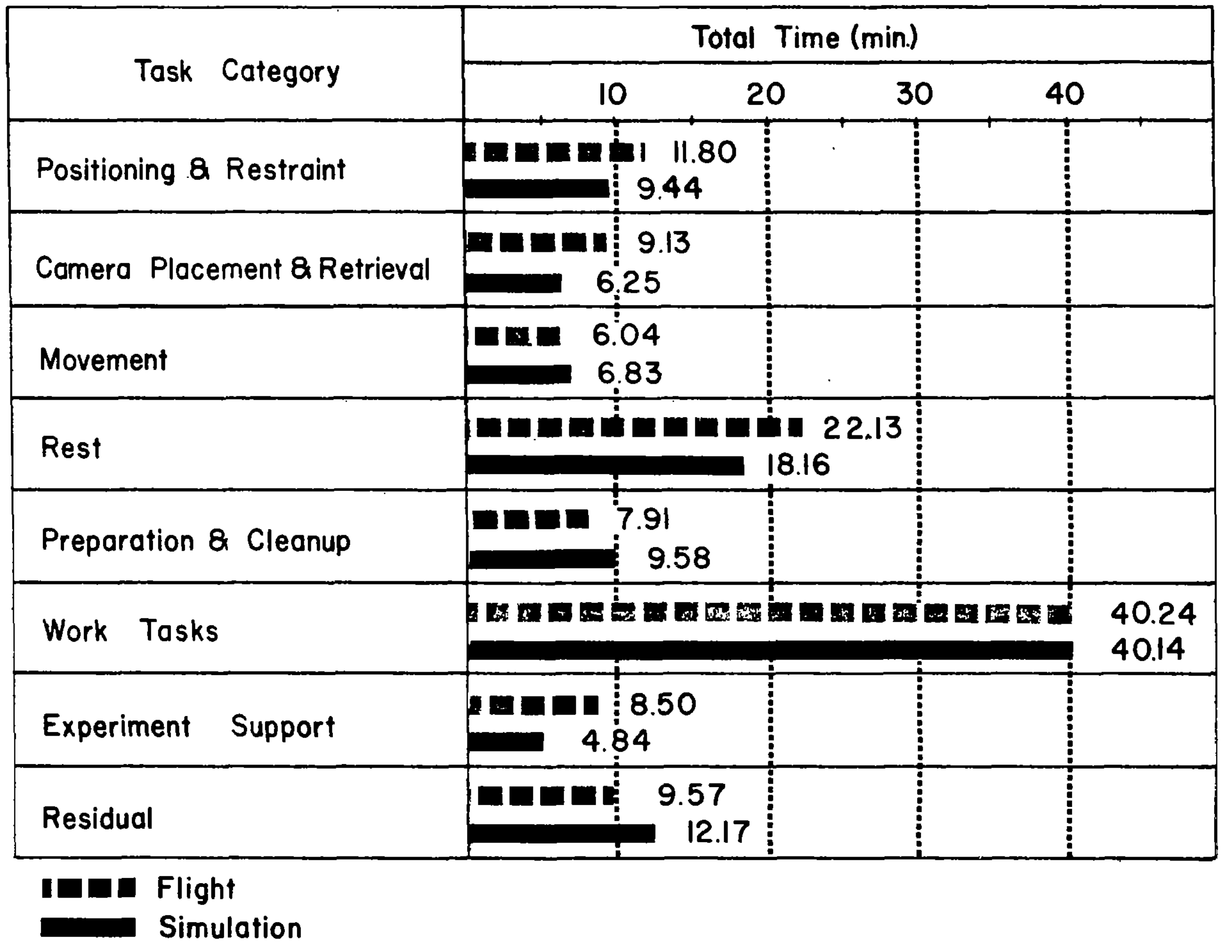


Figure 5-21 COMPARISON SUMMARY OF MAJOR TASK CATEGORY

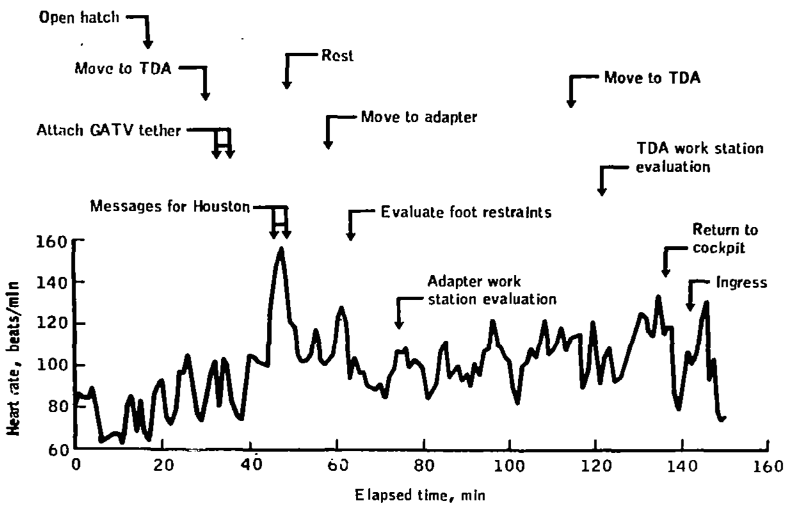


Figure 5-22 HEART RATE VERSUS ELAPSE TIME FOR ORBITAL EVA

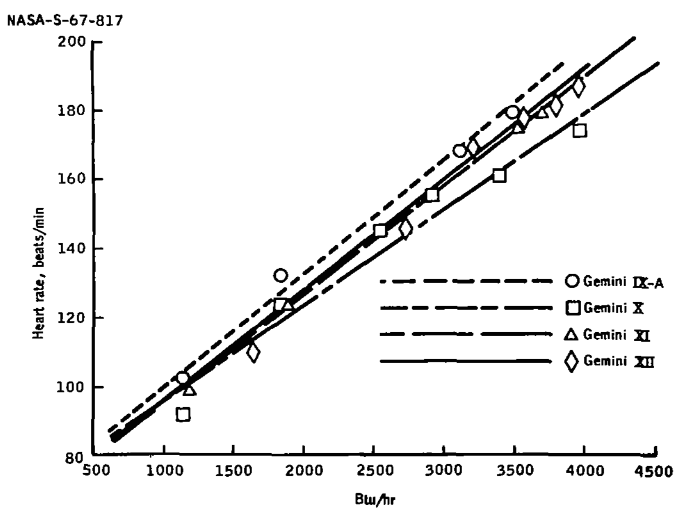


Figure 5-23 PREFLIGHT ERGOMETRY - GEMINI IX - XII

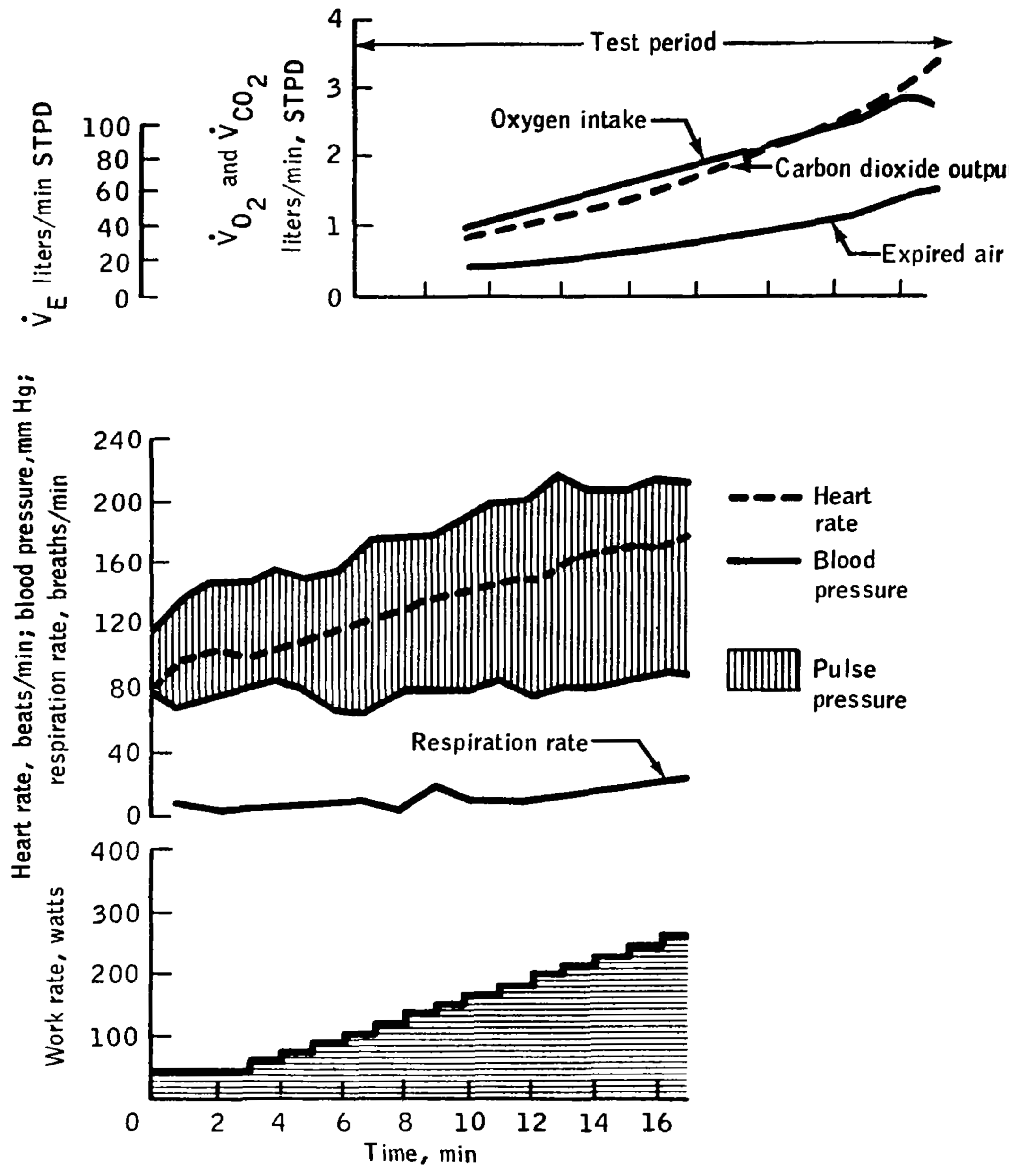


Figure 5-24 OXYGEN UTILIZATION CURVES FROM PREFLIGHT ERGOMETRY

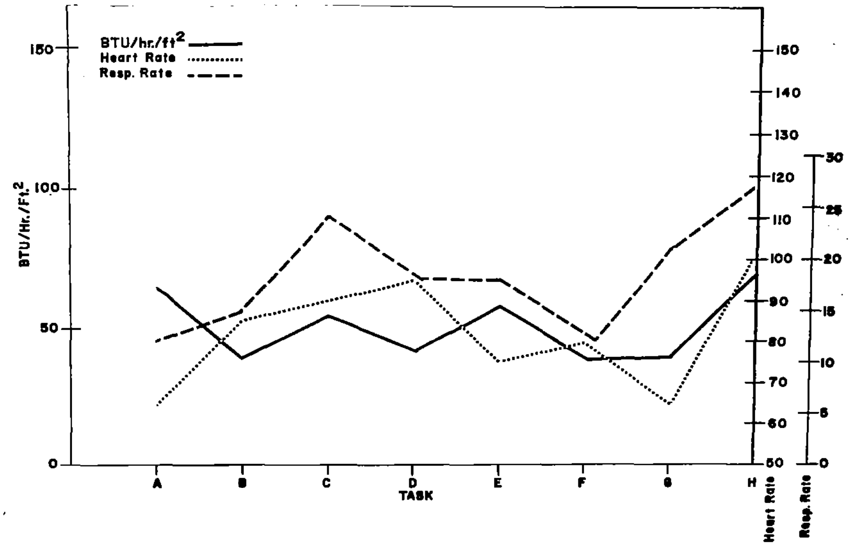


Figure 5-25 GEMINI XII BIOMEDICAL MEASUREMENTS OF THE SIMULATION

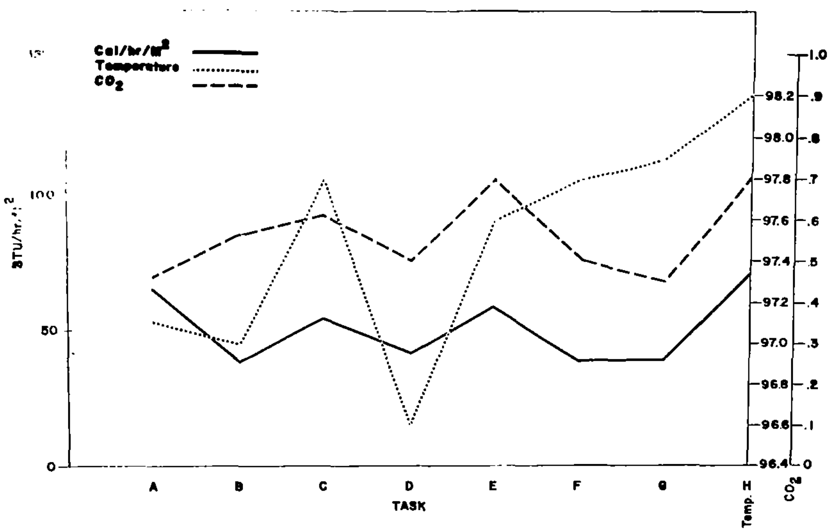


Figure 5-26 GEMINI XII BIOMEDICAL MEASUREMENTS OF THE SIMULATION (de V. WEIR TECHNIQUE)

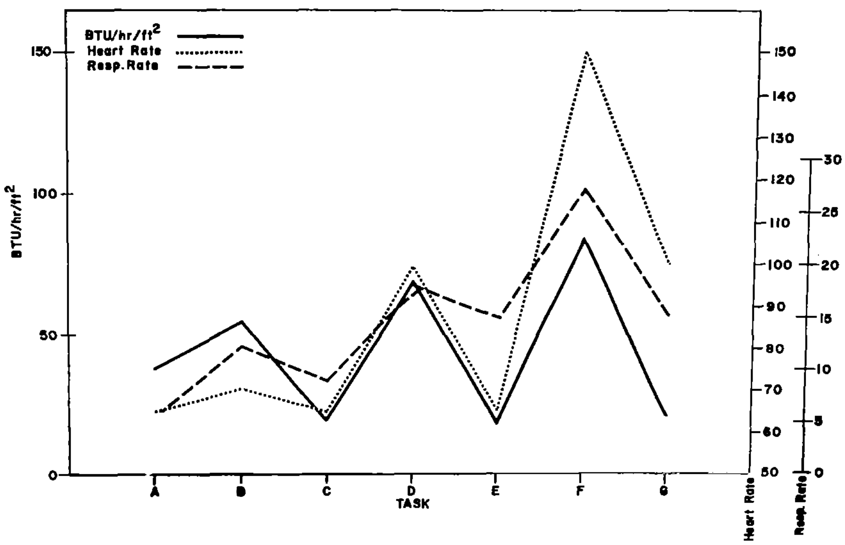


Figure 5-27 PREFLIGHT SIMULATION BIOMEDICAL MEASUREMENTS USING ERA SUBJECT

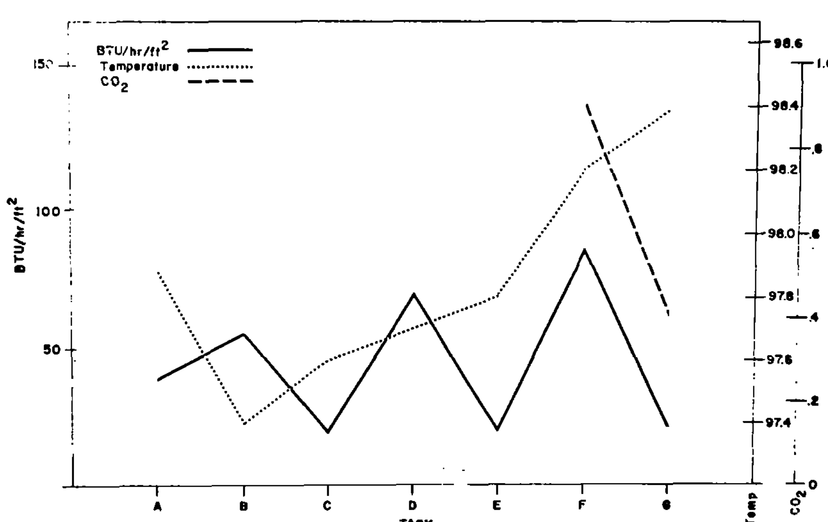


Figure 5-28 PREFLIGHT SIMULATION BIOMEDICAL MEASUREMENTS USING ERA SUBJECT

Cumulative Workload

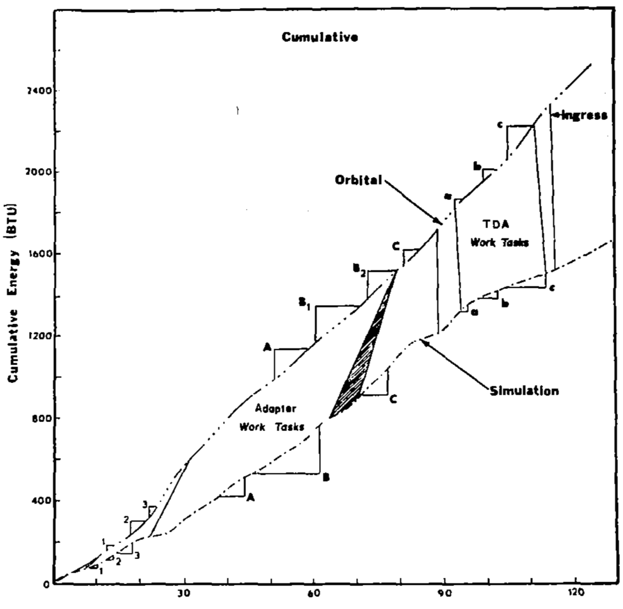


Figure 5-29 CUMULATIVE WORK LOAD FOR THE GT-XII TASK LINE

EFFECT OF AMBIENT PRESSURE ON HEART RATE AT CONSTANT WORK RATE

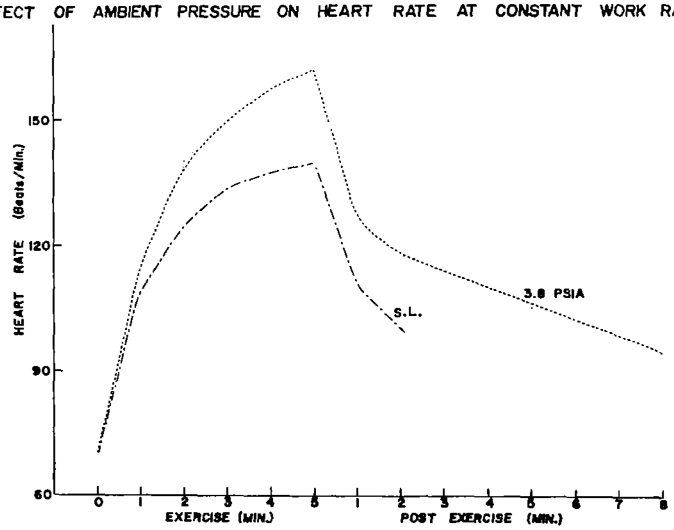


Figure 5-30 EFFECT OF AMBIENT PRESSURE ON HEART RATE AT CONSTANT WORK RATE

EFFECT OF HEAT LOAD ON HEART RATE AT CONSTANT WORK RATES

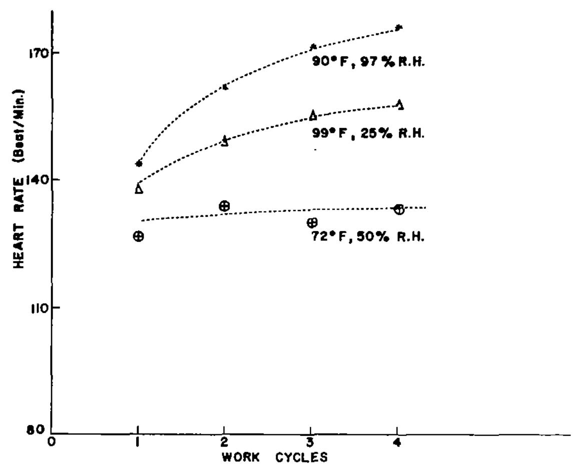


Figure 5-31 EFFECT OF HEAT LOAD ON HEART RATE AT CONSTANT WORK RATES

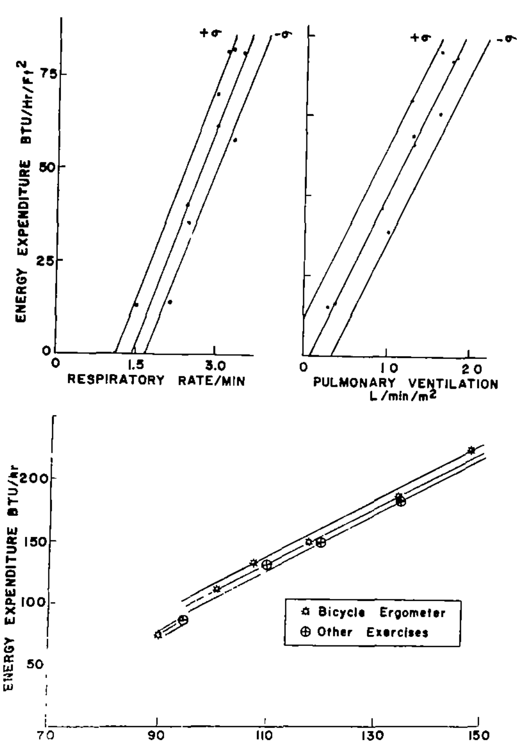


Figure 5-32 SINGLE PARAMETER WORK LOAD CORRELATIONS

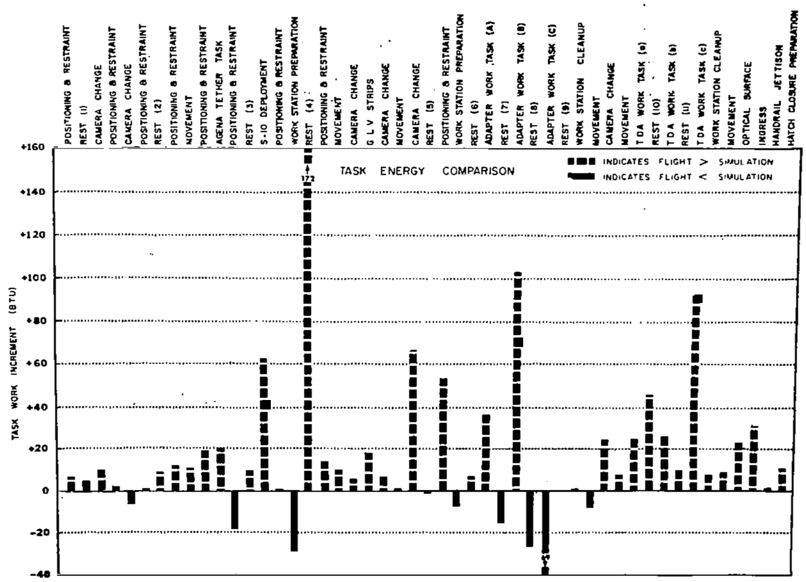


Figure 5-33 GEMINI XII TASK ENERGY COMPARISON

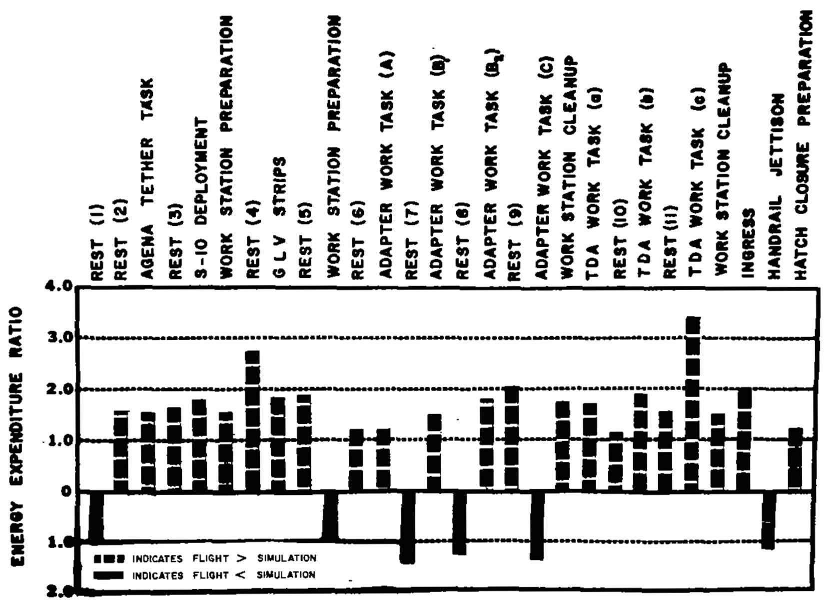


Figure 5-34 ENERGY EXPENDITURE RATIO

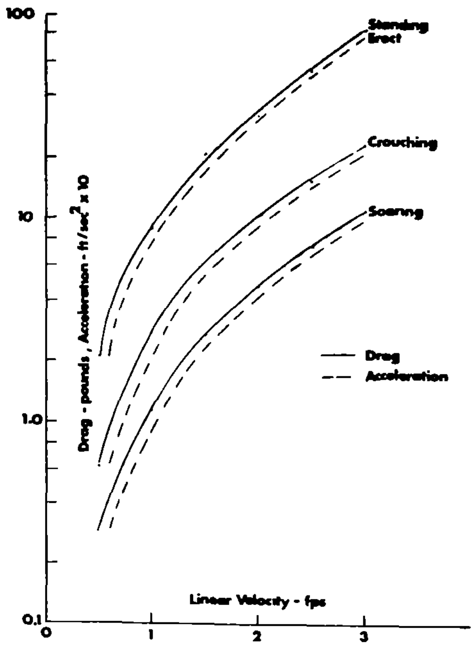


Figure 5-35 CALCULATED DRAG FOR MOTION OF A PRESURE SUITED SUBJECT THROUGH THE WATER

Figure 5-36 ASTRONAUT ADJUSTING POSITION WITH RESTRAINT ATTACHED TO PIP PIN

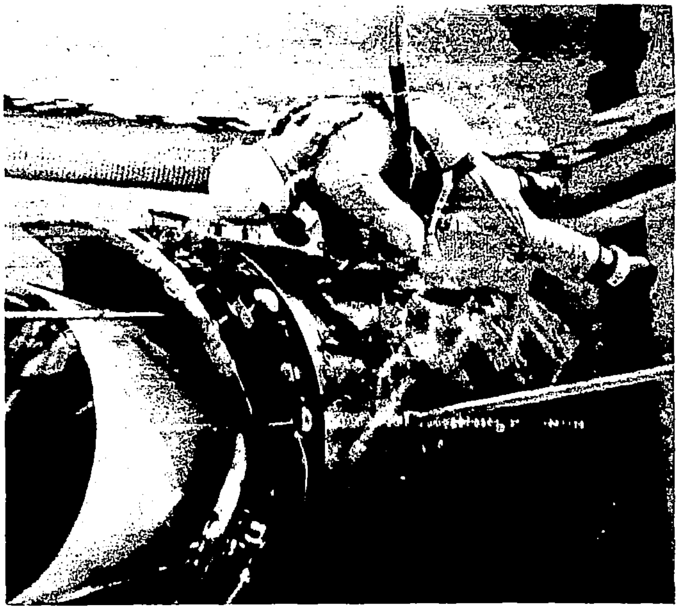


Figure 5-37 ASTRONAUT ADJUSTING POSITION WITH RESTRAINT ATTACHED TO PORTABLE HANDHOLD

The Effect of Restraint On Task Work Load

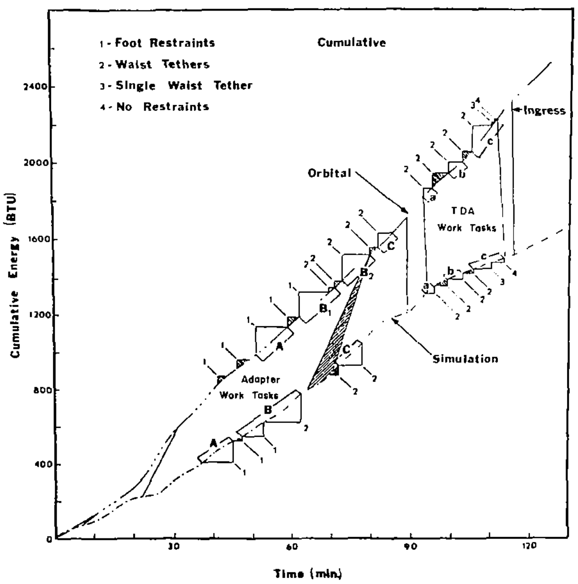
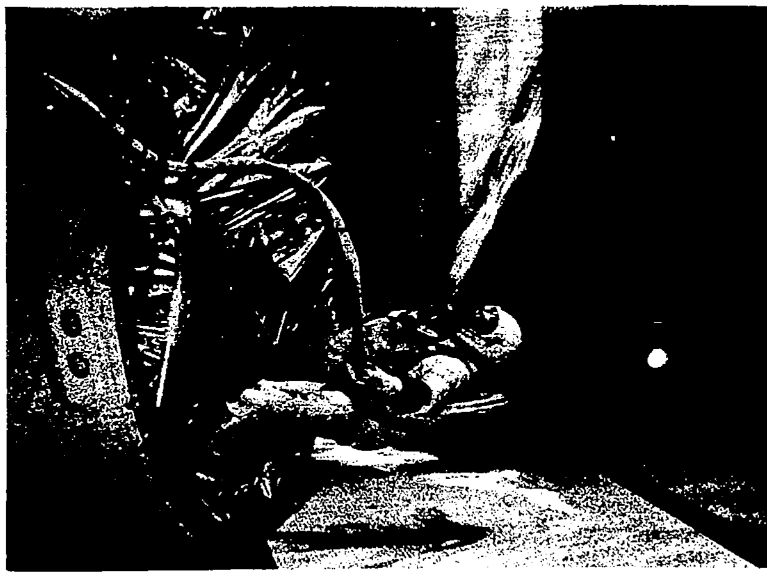


Figure 5-38 THE EFFECT OF RESTRAINT ON TASK WORK LOAD



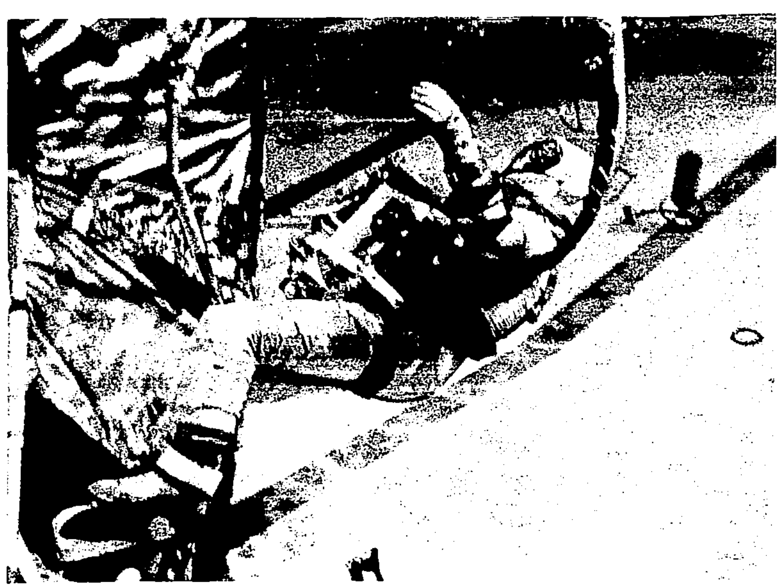
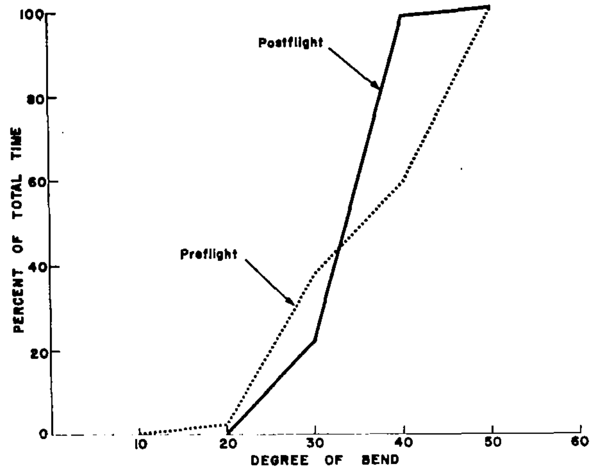


Figure 5 - 39 SUIT MOBILITY EVALUATION IN ADAPTER FOOT RESTRAINTS

Degree Of Flexure At The Hip



Degree Of Flexure At The Knee

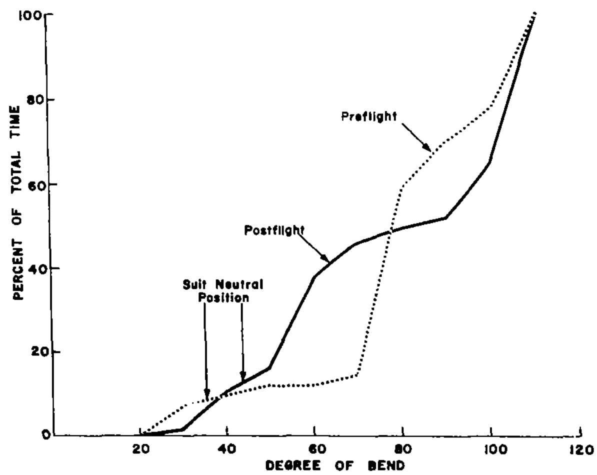


Figure 5-40 SUIT MOBILITY ANALYSIS FOR LEAN BACK TASK

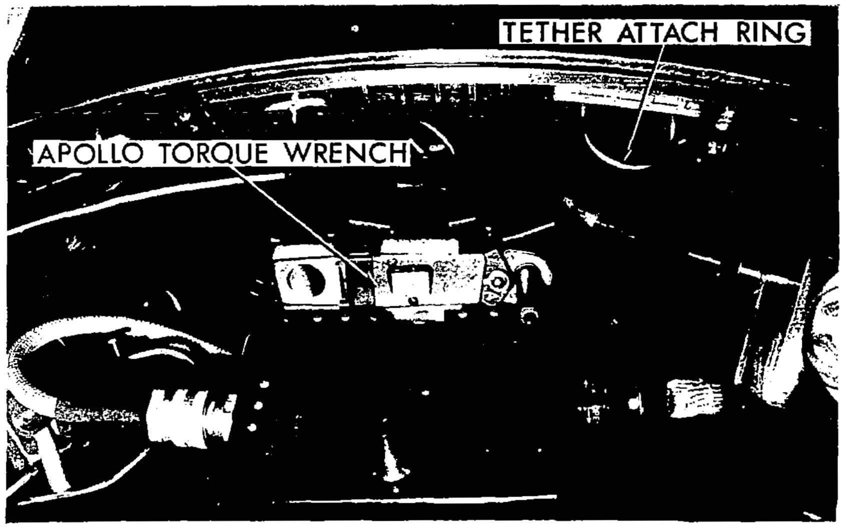


Figure 5-41 APOLLO TORQUE WRENCH

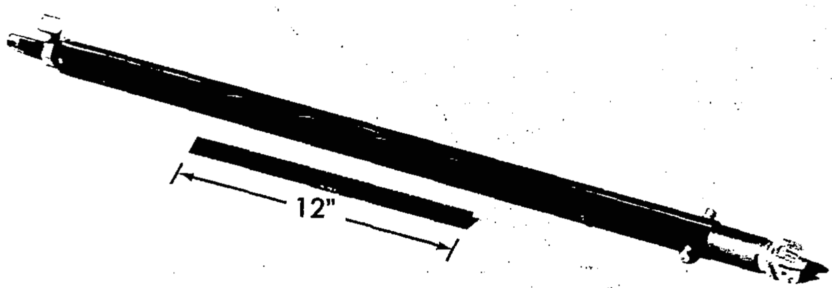


Figure 5-42 TELESCOPING HANDRAIL

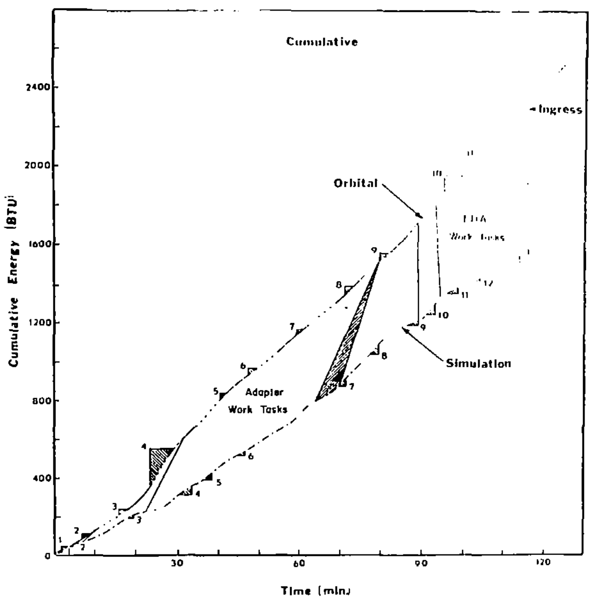


Figure 5-43 COMPARISON OF THE EFFECTIVENESS OF RESTS

Incidence and Duration of Work Tasks

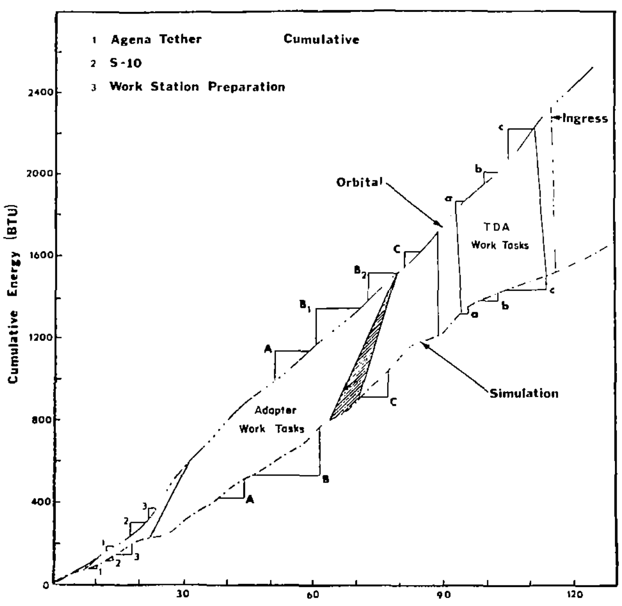


Figure 5-44 EXPERIMENTAL SUPPORT TASKS COMPARISON

6.0-CONCLUSIONS

While water immersion simulation proved to be very useful in supporting the Gemini EVA program, the Gemini EVA program in turn caused a rapid evolution and re-evaluation of the water immersion simulation technique at ERA. The inclusion of biomedical measurements toward the end of the program particularly heightened the value of water immersion simulation of EVA.

In general, the water immersion technique offers a simulation medium which closely compares with actual space performance. Direct numerical correlation must await missions wherein experimental tasks can be designed for direct one for one comparison and where more extensive biomedical instrumentation is included in the flight. The results of the study strongly affirm the validity of water immersion as a simulation tool for support of future EVA and IVA activities.

6.1 - CORRELATION WITH SPACE PERFORMANCE

Time Line - The task time line developed during the water immersion simulation was used to establish target times and was not intended as a rigid performance specification. The tasks were not performed in space in exactly the same sequence as was rehearsed in the water. As an example, the task of collecting deposits on the spacecraft windshield was performed early in the simulation and very late in space. Additional tasks such as the inspection of a vernier rocket were not performed at all in the simulation. There were, however, various task groupings that occurred in sequence and formed the basis of the detailed comparison. These comparisons confirm a very close relationship between preflight training and flights. The data strongly supports the use of water immersion to establish time lines for future EVA.

Velocity - The most serious limitation imposed by the use of water immersion as an EVA trainer and simulator is that of the drag associated with movement. This factor becomes of minor importance for low velocities in the range of 0.5 feet per second or less, since as the velocity approaches zero the drag approaches zero. The velocity associated with a typical movement sequence in the travel down the telescoping handrail, proved to be approximately .25 feet per second in both water immersion and orbital flight. The period involving the greatest distance excursion during EVA was the movement sequence back to the adapter. This sequence is not recorded on film for the flight since there was no camera coverage. Analysis of the water immersion preflight film shows this 9 foot distance to be traversed in 27 seconds for an average velocity of 0.33 feet per second or the same as in the simulation.

While future EVA tasks may result in greater velocities which become a problem in water immersion simulation, the Gemini XII was performed within a velocity range where water drag did not prove to be an important factor.

Kinematics - *The film supplement to this report includes a portion in which a split frame technique has been used to superimpose three reduced size frames on one 16 mm frame. The upper center shows the film from orbit - the lower left shows the film from preflight water immersion - the lower right shows the film from preflight zero gravity aircraft when available. Although the camera angles are different for each view, a careful study shows that performance is very similar in both time and motion between orbital flight and water immersion. The comparison between orbital flight and zero gravity aircraft shows similarity in motion but a major difference in time. Performance in the zero gravity aircraft was always faster but was not a constant ratio. The ratio appears to be task dependent with the time in the zero gravity parabola controlling the speed of the task.*

Work Load - *Biomedical data from preflight has been carefully analyzed and indicates, that for GT-XII type tasks, heart rate is a valid indicator of the relative work load of the astronaut. Oxygen uptake methods require a time to reach equilibrium which is not consistent with the task times experienced. Heart rate, on the other hand, increases during periods when the astronaut is obviously working harder and decreases during periods of lesser activity. In addition, heart rate and respiration rate were the only measures of physiological output made and currently planned for future missions and will, of necessity, form the basis of comparison for tasks in the near future.*

Heart rate comparisons between the simulation and space when determined on the basis of the preflight ergometry, shows that the performance of the tasks in orbit required a higher metabolic output than was required in the simulation, particularly for moderate or higher work tasks. Low level work tasks and rest periods are affected by second order balance considerations in the simulation since the astronaut is not at zero gravity inside the suit.

Since early considerations of water immersion simulation concluded that work in the simulation would be greater than work in space, the GT-XII data showing greater work load in space was unexpected and calls for a review of the simulation versus orbital conditions. A cursory evaluation indicates that thermal load and atmospheric pressure effects may account for the unexpected lower work load in simulation. There was no attempt during the simulation runs to control these effects. Table XXV summarizes the important conclusions developed as a result of this study.

6.2 - UTILITY OF THE SIMULATION

Training - *Astronaut Aldrin accumulated more than 20 hours of water simulation prior to flight including the original GT-XII task line. The last session, 6 hours, was held 14 days prior to orbital EVA. Two weeks after return from orbit he performed a postflight evaluation of the simulation. After each session, an informal de-briefing was held to discuss performance, procedures, and suit operations. As a result of* *these discussions, task sequences were shifted, procedures were altered, and suit operation was modified in order to optimize the astronaut's performance. As a result of this orbital performance preview, Astronaut Aldrin gave special attention to continuously relaxing specific muscle groups in order to be sure that he was not performing unnecessary work. Even after the postflight simulation, the astronaut commented that he was still learning how to work within a pressure suit.*

GT-XII training included Command Pilot Lovell performing the control and monitoring function he performed in space. Subjectively, the crew reported that the simulation training was in part responsible for success of the GT-XII EVA. The results of the analyses performed during this contract support this conclusion. A complete comparison of the available data, however, shows that while the simulation was adequate for the tasks performed during Gemini XII EVA, future tasks requiring greater work loads will require higher fidelity more closely controlled simulation.

Equipment Evaluation - Contracts NAS 1-4095 and NAS 9-6584 were primarily for the purpose of evaluating procedures and training personnel. It was immediately apparent, however, that the simulation also offered a means for evaluating potential flight equipment configurations. The problems of handling portable hardware, such as cameras and tools, became obvious when viewed through the means of high fidelity simulation. This does not mean that each piece of equipment need be an exact copy which has been made neutrally buoyant for high fidelity simulation. Important operating concepts must be faithfully reproduced, however, and where gross uncontrolled motions occur, the hardware must be made neutrally buoyant without changing its geometric characteristics.

Restraints - The specific tasks comprising the EVA time line were not performed in the same sequence in the flight and simulation. Both the number and spacing of the rest periods were different. Consequently, the astronaut's subjective analysis of the task comparison particularly of the value of restraints must be given first priority. Subjectively, the astronaut reported a preference for the molded foot restraints. This preference is partly due to the combination of these restraints with the Gemini suit which is relatively inflexible in the foot and leg area thus providing a preferred attitude position maintenance characteristic. Waist tethers provide control of the maximum excursion distance between the tether points and the astronaut but provide little control over attitude. Future plans for the use of the molded foot restraints should take into account that the Apollo suit, being reasonably flexible in the foot and leg area, will not provide the same position maintenance characteristics as did the Gemini suit.

Another factor complicating the evaluation of restraints is the length of individual tasks. Since the individual tasks were of short duration and were not performed in the same sequence in simulation and space, it became advantageous to evaluate the contribution of restraints in the other Gemini EVA's. In the Gemini program, the only long term EVA task performed in a repetitive sequential manner was the AMU activation task. Information on this task included:

(1) Astronaut Cernan performing a postflight evaluation of GT-IX using foot stirrups.

(2) Astronaut Aldrin performing preflight GT-XII using molded foot restraints.

(3) ERA subject performing GT-IX and GT-XII with foot stirrups.

(4) ERA subject performing activation tasks with no restraints.

The difference between GT-IX and GT-XII activation was the type and location of the foot restraints. GT-IX had stirrups mounted on a bar relatively high while the GT-XII version used the molded foot restraints mounted below the AMU. Comparative evaluation supported by subjective comments strongly suggest that the overall task of AMU activation was easier without restraints.

The unrestrained subject moves during the task and optimally positions the suit relative to the required subtask. The GT-IX restraint requires gross suit bending to reach lower portions of the AMU and the GT-XII restraint requires much higher level effort due to the preferred work location of the torso (a suit problem reported by E. Aldrin during debriefing). In summary, restraints must be considered for future mission requirements on the basis of their value to the performance of particular tasks.

Table XXVI summarizes the utility of water immersion simulation relative to the Gemini EVA program. Starting with the Gemini IV EVA with no contribution, water immersion simulation continually had an increasing role in support of the EVA. A major value of the simulation proved to be the capability to visually preview space performance, thus allowing mission planners to synthesize and coalesce the flight plan into a final task line with assurance that the astronaut would not be required to drastically alter his rehearsal procedures. Further, the results indicate that candidate hardware configurations can be adequately evaluated prior to use in space. Also, the astronaut need not be required to pre-evaluate each piece of hardware and choose which hardware configuration and procedure he will us. Rather, a repetitive analysis can be made utilizing personnel of equivalent performance capability to narrow down the range of choice.

Water immersion simulation should form the basis for the development of time line and hard data relative to equipment and equipment layout for future missions. The Gemini XII EVA consisted of a well identified set of tasks of relatively low work load interspersed with many rest periods. Also, the task took maximum advantage of restraint techniques evaluated prior to the flight. Care must be exercised in applying these techniques to new areas of EVA requiring high work loads. Continuous water immersion simulation is required as well as support from other modes such as the zero gravity aircraft to supply information unobtainable from water immersion simulation.

TABLE XXV

CONCLUSIONS

1. WATER IMMERSION SIMULATION - TRAINING CONTRIBUTED MATERIALLY TO THE SUCCESS OF GEMINI XII
2. FOR NEAR FUTURE EVA TASKS THE WATER IMMERSION TECHNIQUE SHOULD BE THE PRIMARY SIMULATION MODE
3. TIME CORRELATION IS ADEQUATE WITH WATER IMMERSION SIMULATION
4. HEART RATE - WORKLOAD CORRELATION IS THE PRIMARY METABOLIC MEASURE DUE TO SHORT TASK TIMES AND SLOW EQUILIBRIUM RESPONSE TIME OF OXYGEN UPTAKE METHOD
5. MODERATE TO HIGH WORK TASKS EXHIBIT GREATER HEART RATES IN SPACE
6. LOW WORK TASKS E.G. RESTS ARE AFFECTED BY 2nd ORDER BALANCE CONSIDERATIONS IN WATER
7. AIRCRAFT SIMULATION IS VALID KINEMATICALLY BUT REQUIRES TIME INCREASE
8. EXACT NUMERICAL CORRELATION REQUIRES RESOLUTION OF THERMAL AND PRESSURE EFFECTS

TABLE XXVI

SUMMARY OF GEMINI EVA RESULTS AND APPLICABILITY OF WATER IMMERSION SIMULATION

FLIGHT	OBJECTIVES	PERFORMANCE	COMMENTS	APPLICATION OF WATER IMMERSION SIMULATION
GT-4	-Feasibility -E.V. Motion (HHMU)	Demonstrated mans capability to perform EVA	-Low task workload	-None
GT-9A	-E.V. Motion (AMU)	Terminated early due to excessive workload	-Problems of timeline and training validity -Inadequate body restraint system	-Postflight evaluation by astronaut and ERA subjects -Demonstrated preliminary utility of water immersion training
GT-10	-E.V. Motion (HHMU) -Retrieval of experiments	First transfer between spacecraft Inadvertant loss of equipment Terminated early due to spacecraft constraints	-Emphasized need for simulation -Body restraints, handholds and equipment tiedowns	-Partial preflight simulation by ERA subjects only -Showed possibility of equipment loss
GT-11	-E.V. Assembly and maintainence tasks	Terminated early due to excessive workload	-Emphasized need for pilot training in water immersion mode -Raised serious questions as to EVA workload capability	-Preflight simulation by ERA subjects only -Partially restructered timeline and operation -Pilot performed task different than ERA subjects
GT-12	-Evaluation of: restraints, potential hardware, planning and operational procedures	Successful performance of all tasks Workload remained below prescribed limits	-Proved utility of water immersion training technique -Established adequate basis for future EVA	-Extensive preflight and postflight training by astronaut, supported by ERA subjects -Task simulation closely corresponded to flight performance

7.0-RECOMMENDATIONS

The successful use of water immersion simulation in the Gemini program supported by the analysis of this study provides the basis for the major recommendations of this contract. In some instances, these recommendations are a direct result of the data developed during this contract. Certain of the recommendations are synthesized from data developed during previous ERA contracts with the Langley Research Center. The major recommendations are summarized in Table XXVII.

Water immersion simulation should be used as the basic simulation mode for the zero gravity extravehicular tasks for both the Apollo and the Apollo applications programs. For these programs, the water immersion simulation mode should be used to establish basic time lines for continuous task performance. The film record of the task performance should then be used to determine the need for additional simulation in other modes, particularly the zero gravity aircraft.

Water immersion simulation should be used to develop one or more human factors experiments for near future missions, and to provide a complete preflight data base for evaluation of the results from the experiments. In this manner, the need and justification for the experiments can be clearly identified. Preflight evaluation can be performed under conditions admitting high fidelity measurement techniques which can then be adapted to the orbital experiment. In this manner, the data return from space can be properly evaluated after the flight, yielding the maximum possible efficiency.

Although water immersion simulation has proved extremely useful, its value to the space program will be limited until additional information from space flight experiments is available. It is important that the water immersion simulation mode be thoroughly understood so that it may be used in an optimum fashion. Additional information needed for optimum utilization of the water immersion technique includes:

(1) *Previously uncontrolled simulation parameters of pressure and heat load effects must be evaluated and a resultant technique be developed to more closely simulate spacecraft environmental factors.*

(2) *A consistent metabolic rate measurement system must be developed so that future space experiments can be properly preassessed in the simulation and be properly correlated after flight. This system must be compatible with astronaut performance criteria.*

(3) *Additional study is needed to determine the exact numerical correlation between water immersion simulation and zero gravity aircraft simulation and one gravity walkthroughs.*

(4) The merits of the air-filled versus water-filled pressure suits must be compared on a specific task basis to determine task applicability.

(5) A careful study should be made to determine those potential astronaut tasks applicable to water immersion simulation. These should include both IVA and EVA categories.

Astronauts should be trained for zero gravity extravehicular activities by means of water immersion simulation. Each astronaut candidate for extravehicular activities should be required to have a minimum of 20 hours pressurized in water simulation performing tasks which have been determined to be similar to those tasks he is expected to eventually perform in space both from a functional and activity level. A measurement system should be devised for scoring performance to assist in planning the exact configuration of the space tasks.

TABLE XXVII

RECOMMENDATIONS

- DETERMINE CONSISTENT TASK FOR SPACE EXPERIMENT
- PREFLIGHT EVALUATION OF SPACE EXPERIMENT
- METABOLIC RATE MEASUREMENT SYSTEM DEVELOPMENT
- RESOLVE PRESSURE-HEAT LOAD EFFECTS
- CORRELATION OF WATER SIMULATION WITH GROUND-A/C
- EXTENSION TO INTRAVEHICULAR AND REDUCED GRAVITY TASKS
- EVALUATION OF "WATER FILLED" SUIT
- DETERMINATION OF TASKS APPLICABLE TO WATER SIMULATION
- APOLLO EVA TASK SIMULATION
- AAP TASK SIMULATION

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